GUIDE FOR INDOOR AIR QUALITY SURVEYS

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INTRODUCTION

Purpose

This technical report provides guidance for performing indoor air quality (IAQ) surveys at base level. It provides Bioenvironmental Engineers (BEEs) and Public Health Officers (PHOs) with checklists and other aids for effectively running an IAQ program keeping occupational health issues in mind. This report replaces AL-TR-1992-0016, Guide For Indoor Air Quality Surveys. However, much of the information in the 1992 IAQ Guide is still current. Where applicable, some sections have been updated, whereas some new sections have been added to address problem areas the AFIERA Industrial Hygiene Branch has experienced on IAQ surveys. Updated information is provided for areas that have been of much interest, such as heating, ventilating and air conditioning (HVAC) duct cleaning and microbiological contamination.

Background of IAQ Concerns

Poor or inadequate indoor air quality, are terms used to describe nonindustrial indoor spaces where occupants complain of health problems which seem to be correlated with building occupancy. Therefore, occupant complaints appear while inside a certain building and lessen when they leave the building. In the United States Air Force (USAF), the primary areas of concern are office buildings, although base housing may also have its share of IAQ concerns. An IAQ issue begins when decisions are made about design, operation, or maintenance of a facility without considering the impact on workers' health or comfort. The result can be reduced productivity and low morale because workers suffer daily from physical symptoms such as sinus congestion, drowsiness, lack of concentration, dry itchy skin, eye irritation, intolerant temperatures and allergies.

When the situation warrants investigation. The BEE, PHO, CE and facility manager should survey the building and its occupants in search of a plausible cause of such physical complaints. Corrections may cost substantial sums of money and sometimes be seen as contrary to policies in place regarding energy conservation or operation and maintenance of ventilation systems. Therefore, to be successful in remediation of IAQ problems, it is essential the BEE, PHO and civil engineer (CE) operate as a team with an effective game plan.

Scope

The primary purpose of this report is to provide the technical guidance necessary to complete reliable IAQ surveys. Roles and responsibilities of all team players and the steps necessary to perform proper IAQ investigations will be discussed. This report will stress the importance of teamwork to run an effective IAQ program from the occupational health perspective. Supporting documentation and IAQ areas of interest are added for individuals desiring more information.

CONDUCTING AN IAQ SURVEY

Team Players

The quality of a survey reflects the capabilities of the survey team. We believe the best approach is the Team Aerospace approach, and that the BEE, Occupational Health Physician/Flight Surgeon, and PHO all have specific expertise to apply to the problem. They must work closely with Civil Engineering to identify and correct problems. With appropriate team effort, quality environments can be achieved and maintained. Quinlan et al. (1989) recommends that a team include members with expertise in medicine, industrial hygiene, epidemiology, microbiology, ventilation, and building maintenance. They also believe it is important to involve management, the building manager or owner, and employee representatives. In fact, Quinlan et al. state that the most important factor in the long-term solution of building-related problems is effective ongoing communication between the investigating team, the building manager and employees. Besch and Besch (1989) put it another way: "An IAQ problem should be considered a crisis and should be managed as such."

Investigation Protocols

Several authors have published protocols for conducting IAQ investigations. Quinlan et al. (1989) and the Ontario Ministry of Labour (Rajhans, 1989) have developed comprehensive protocols, including questionnaires and checklists. Burton (1991) has published a series of articles in simple language that includes an easy investigation protocol. Our recommended protocol, based on our experience and the protocols listed earlier, can be found in the following section.

Steps for a successful survey include an initial walk-through evaluation of the building, possible self-administered questionnaires and personal interviews with the employees, air sampling if necessary, a detailed report of findings, recommendations, and follow-up visits to assess the success of the recommendations (Quinlan et al., 1989). Quinlan et al. also recommend using a cross-sectional analysis of the interviews and air sampling results to develop conclusions and test hypotheses. A cross-sectional analysis determines frequencies of symptoms by area of a building, job description, or ventilation unit and compares to air sampling results in affected areas as well as control areas. Control areas can be "healthy" buildings, or unaffected parts of buildings. The outdoor air is also a useful control (Burge and Hoyer, 1990).

We have found that the most important functions of the physician, BEE and PHO in any IAQ survey are education and communication. Building occupants need to know what is causing their health problems and what they can do (or avoid doing) to improve their environment. The impact of building design, maintenance, and operation on IAQ needs to be realized. There is a strong relationship between HVAC maintenance and the comfort of workers. Management (Base and Hospital Commanders, Unit Commander, or supervisor of affected workers) must be informed about the workers. When all three groups know the primary causes of problems, they can communicate effectively and achieve effective results.

AFIERA/RSHI Protocol for Comprehensive Indoor Air Quality Investigation

1. The BEE should first tour the building and check for any obvious indications that could lead to an IAQ problem. Inspect each air handler with an engineer from CE who specializes in HVAC systems. They should visually verify HVAC conditions. The expertise of the HVAC engineer is needed to ensure that the HVAC system is thoroughly and properly inspected. Furthermore, it is important to have CE involved from the beginning because they will often be responsible for the repairs, or will have to advocate for the money to fix the problem. Some of the items to look at in each air handler are:
    - Are the fresh air intakes located away from pollution sources, such as busy streets, loading docks, or exhaust vents?
    - What is the designed minimum outdoor airflow rate? Does the system currently meet this minimum?
    - Are the fresh air dampers really open during normal operation? Are the damper controls connected and functional?
    - Do the temperature controls work properly?
    - Is there a comprehensive maintenance schedule, and is enough manpower available to perform it? Are provisions made for the cleaning of cooling coils and drain pans? Are the air handling and fan-coil units easily accessible for inspection and preventive maintenance?
    - Is the HVAC system reasonably free of dust, oil, and fibers, including the cooling coils, ductwork, all plenums and chambers?
    - Do the air filters have a minimum efficiency reporting value (MERV) of not less than 6?
    - Is the HVAC system free of standing water?
    - Are the drip pans under the cooling coils double sloped and made of a non-corrosive material? Is the drain mounted and functioning in a manner that prevents water from accumulating in the pan? Are the drip pans free of microbial growth and evidence of past growth?

- Is there a return fan? If so, are the air handlers positively pressurizing the building (i.e., is the supply fan stronger than the return fan)? If the supply fan speed can vary, is there fan-tracking control so the return fan is never stronger than the supply fan? Does it seem to work?
- Are contaminants from the mechanical room (e.g., heater) exhausted so they cannot enter the air handler? If the mechanical room acts as a return air plenum, is it free of trash, dirt, standing water, and chemical storage?
- If insulation is used inside air handlers, is it fixed so fibers cannot enter the air handler? Is it kept dry? Are the sections of the air handlers and ductwork that are expected to become wet during normal operation constructed of a material with cleanable surfaces?
- Do all rooms have supply air vents? Do they deliver the designed airflow?
- Are the supply and exhaust vents in rooms free of dust, dirt, and obstructions?
- Does the diffuser distribute supply air evenly? Does the office setup (room dividers, etc.) allow supply air to reach workers?
- If there are mechanical dampers for the room supply vents, are they open wide enough? If there are automatic dampers, such as variable air volume (VAV) boxes, do they work and are they calibrated? (There are various types of VAV boxes. Some open and close the damper based on room thermostat readings. Others work on a pressure principle. Ask the HVAC engineer to explain the ones you encounter -- when they open, how wide, etc. Then, verify they work as described.)
- Are the walls and ceiling free of water stains? If not, what caused the stain? Has it been fixed? Is there visible microbial growth?
- Is this a smoking-free building? If not, is the tobacco smoke prevented from getting into the main air handlers?

2. If there are complaints of odor or irritation, find and remove the source. Typical sources are untrapped drain lines connected to the sewer, gas-fired heater exhaust, new furniture or carpet, off-gassing from office equipment, stagnant air, insulation fibers, and external emissions brought into the building by the fresh air intakes. Possible screening samples to collect are methane, hydrogen sulfide, carbon monoxide, hydrocarbons, ammonia, formaldehyde, particulates (dust and fibers), sulfur dioxide, nitrogen dioxide, and ozone. Ensure direct reading instruments are calibrated. If any of samples are significantly above outdoor levels, trace the source and remove it. If the samples are not above outdoor levels, use the data for negative documentation.

3. Mold or bacteria contamination can be a significant contributor to IAQ problems. Allergic responses are the most common complaint. Air sampling to confirm the presence of microbes is unnecessary -- signs of contamination such as growths in the drain pan, a mold odor, or water-stained ceiling tiles are enough. The primary concern is to identify the cause of the contamination and repair the affected areas. A moisture meter can be used to assess the amount of moisture in construction materials. It is non-destructive and an effective means of determining the scope of water damaged materials. If the decision to sample is made, refer to the guidance provided in Appendix D microbial sampling guidelines.

4. If needed, to back your findings thus far, measure the carbon dioxide concentration, relative humidity, and temperature. When these “comfort" parameters fall outside their ideal range, complaints begin. The ideal ranges are: 1000 ppm CO_2 or less, relative humidity between 40% and 60%, and temperature from 20 to 24.4^oC (68 to 76^oF). Take measurements in several representative rooms for each air handler (both affected and unaffected rooms). Also take measurements outside (for comparison), and in the return air plenum if possible. A CO_2 meter with data logger should be run for 24 hours in the return air plenum and in an affected area. Make sure the meter is calibrated. The CO_2 concentration will rise exponentially as the workday begins and will usually stabilize 3 to 4 hours later. At least four readings per representative room are recommended for each comfort parameter. Spread the measurements throughout a day when the air handlers are in their usual operating mode. If there are two (or more) modes, sample when the outside air is minimized and when the fresh air dampers are open the widest.

5. Upon completion of the initial inspection, Team Aerospace should meet to discuss the results and formulate a game plan. In most cases the IAQ problem will be identified during the walk-through inspection. Additional testing is not required if you feel the cause of the problem is known. However, it remains of the utmost importance to communicate with the building occupants the findings of the inspection. Risk communication will often make a successful remediation much more likely. If you have been unable to identify an obvious cause, or the complaints associated with the building do not correlate with your findings, additional testing may be required.

6. An IAQ questionnaire can help determine if the building occupants feel the indoor environment is affecting their health. However, a questionnaire is not needed in most cases and should only be used when it will make a difference in your course of action or has been command directed. An example questionnaire is available in Appendix A. A bubble sheet version of the questionnaire in Appendix A is available upon request from AFIERA/RSHI. Return completed bubble sheet questionnaires to RSHI for scanning and interpretation. The questionnaire allows occupants to select symptoms they feel are building related. As a control measure, some of the symptoms they are allowed to choose are unrelated to IAQ. If a questionnaire is used, it is important to obtain responses from a representative sample of the building population. For instance, there should be responses from appropriate percentages (based on the demographics of the building occupants) of men and women; officer, enlisted, and civilian; older and younger; blue and white collar; sick and well; from each floor and/or section of the building; etc. In general, if you have decided to use a questionnaire, you should offer it to everyone in the building. In the case of a very large building with hundreds or thousands of occupants, a smaller representative sample is reasonable. The questionnaire response rate is also important. Blindly sending out questionnaires without local buy-in (managers, unions, workers, etc.) and an accompanying education program will often result in a poor response rate, on the order of 10-20 percent. Letting people know why you need their input, the importance of honest answers, how privacy will be maintained, and what you will do with the information they provide will dramatically increase the overall response rate. There is no magic numerical goal, but 50% or more will usually provide good information that will

help in your assessment of the building. A dissatisfaction rate above 20% is an indication of unacceptable indoor air quality as defined by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) in 62-2001, Ventilation for Acceptable Indoor Air Quality.

7. In rare occasions, the PHO or Occupational Health Physician/Flight Surgeon may formally interview workers who have reported symptoms resulting from exposure to the building environment. This can serve two purposes. First, the interviews will independently check the questionnaire results, help narrow down the cause of the problem and identify the most affected building areas. Second (and just as important), the workers will perceive that someone cares and understands, thus reducing anxiety over the problem.

8. Compare results of the inspections and air sampling to questionnaire and interview data. Compile the collected data plus conclusions and recommendations into a report. Use the report to generate action items. Use the troubleshooting guideline in Appendix C to aid in the recognition, evaluation, and control of IAQ problems.

9. Conduct an out brief including management and employees. Risk communication is one of the most crucial parts of the survey. Generally, people who show an interest in this meeting will often be the employees with concerns. Reassuring them that their problems are being addressed is of the utmost importance to a successful remediation. Overhead slides of sampling results and photos from the survey can add support to the recommendations. Conclude the out brief with a list of action items that each office of responsibility will accomplish.

10. The last step is to follow up on the action items. A month or so after the survey call or visit the building and talk to the individuals who were noted to have symptoms or conditions that may be related to the workplace environment. Find out if conditions have improved after recommended changes have been made. Follow up at 6 months and one year to check on the situation.

Risk Communication

Risk communication is an integral part of occupational and environmental health, including indoor air quality evaluations. A simple working definition of risk communication is, **"Listening to people and honestly answering their questions in a way they can understand."** More than half of good communicating involves listening! The goal is to allow for effective communication regarding risk issues, not a one-way communication monologue (*e.g.*, presentation) of what you believe they need to hear.

Environmental risk communication involves the use of many tools and techniques to form and deliver effective messages. Such messages may:

- Inform and educate,
- Allay fears,
- Lay foundation for informed decision making, and
- Inspire people to behave in a particular way

Table 1. Components and Examples of a Good Communication Plan

Component	Definition/Example
Purpose	Establish a coordinated plan to respond to concerns about mold and health to people working in bldg #XXX.
Objective	Provide accurate, consistent messages about possible health effects of mold to people working in bldg #XXX.
Points of Contact	Usually public health officer, physician, and/or PA.
Stakeholders	List of people who are potentially exposed and those with a vested interest in doing the right thing and with the requisite authority, e.g., wing CC, bldg facility manager, MDG/CC.
Background Material	Overview of the events leading to the present situation.
Target Audiences	Identify who needs to hear your messages and profile them (demographics, knowledge, attitudes, perceptions, behaviors, etc.). Usually bldg occupants, medical staff, wing leadership, CE, and others.
Key Messages	Determine your most critical messages (no more than 3.) Example: The water in bldg #XXX is safe to drink.
Tactics	1. Identify technical and PA leads. 2. Prioritize various audiences. 3. What is the best medium to use (poster, fact sheet, newsletter, TV/radio interview, Town Hall, etc.?) 4. Identify spokesperson(s). Note: often not the technical expert. Must be credible, empathetic, culturally aware, good at conflict management, and a capable communicator under stress. 5. Decide how to measure the effect of the messages.
Draft Statements/Messages	1. Brief paragraph describing key point/objective. 2. List three important, simple facts or statistics 3. Use language appropriate to the target audience 4. Highlight a key message/conclusion the audience should hear (so the spokesperson can repeat it.) 5. Identify POCs for follow-on questions.
Questions and Answers	Create a list of likely questions and craft answers in advance. Good sources include feedback obtained from bldg occupants and various stakeholders.

In order to communicate effectively, you must have a plan. Even though creating a plan may seem unnecessary, it makes success much more likely. It is valuable to draft a basic outline early in the IAQ evaluation process. This is especially critical if Team Aerospace is asked to consult late in the process, i.e., the situation is highly charged with emotions and distrust. In such cases, you will want to insure all members of Team Aerospace are aware of the issues and how they are being resolved. Of equal importance is to involve your local public affairs staff early. AFIERA can provide additional risk communication consultative support through a number of services, as requested (e.g., risk communication plan and fact sheet development, document review, and on-site assistance.)

Plans are not static; they must evolve over time. Reassess them frequently and make modifications based on how the situation may have changed. Also, don't work in isolation. Other opinions are often very helpful, so talk to public affairs, MAJCOM staff, AFIERA, and the concerned individuals early and often.

Conclusions

We have found that the three most frequent sources of unacceptable IAQ are: inadequate design and maintenance of HVAC systems, insufficient fresh air, and high/low relative humidity. Assessment of the ventilation systems, identification and evaluation of the sources of contamination and correlation of the medical data should be done as a team. Occupancy complaints should be taken seriously and surveys performed with the utmost professionalism. The information from each survey should be documented and filed for future reference. Communication is critical for the success of a good indoor air quality program. The cost of construction, operation, and maintenance of a good HVAC system is well worth the money.

It is important to remember that standards are only guidelines, whether American National Standards Institute (ANSI), ASHRAE, or government agency. Professional judgment must supersede any criteria that are proving to be inadequate. The ultimate baseline, as ASHRAE states is human health and acceptability. Through education and communication we are learning to balance the quality of the indoor environment, increase productivity and conserve our resources.

Recommendations

Our experience with IAQ problems and our findings lead us to make the following recommendations:

1. Configure air handlers to maintain CO_2 levels below 1000 ppm. Ideal range is 600 ppm or below.

2. Maintain relative humidity levels between 40% and 60%.

3. Maintain temperature between 20 and 23.8^{o}C (68 and 76^{o}F) and follow guidelines from ASHRAE Std. 55-1992 or its updates.

4. Use the survey protocol outlined in this report and work as a team with Civil Engineering and the building manager to achieve the maximum positive results.

5. Ensure the Air Force smoking policy is in effect and smoking areas are away from the building and the fresh air intakes.

6. Check the occupancy rates of the buildings and if overcrowding is a problem, call the Safety Office to verify and help resolve this issue.

7. Use common sense approaches to the problems in all of the above recommendations.

DISCUSSION

Getting the Proper Perspective

According to AFI 48-145 (1999), the purpose of the Air Force Occupational Health Program is to enhance overall mission effectiveness by protecting human resources in the workplace, reducing costs, and improving performance. This broad objective includes many projects with higher priorities than IAQ investigations. It is important however, to find the time to investigate IAQ complaints for several reasons. First, once an IAQ concern arises, workers are affected almost daily by symptoms that reduce productivity and lower morale. Second, ignoring minor IAQ voiced concerns can lead to the development of serious illness. Third, early involvement and action by command authority to any voiced IAQ concern has excellent potential for complete success in solving the problem and assure worker safety and health.

Fundamentals

We spend 85-90% of our time in some form of shelter, i.e., home, office, car, or school (Stolwijk, 1990). Therefore, it is obvious that the quality of the indoor air can have a significant effect on our health. A comprehensive study of over 4,000 British office workers in buildings <u>without</u> known problems (Burge et al., 1987) makes this clear. Researchers reported that 57% of the workers complained of lethargy. Blocked nose, dry throat, and headache were listed as frequent symptoms by 40 - 50% of the workers, and about 25% of the workers suffered from itchy/dry eyes, runny nose, and flu-like symptoms. In a study of United States (U.S.) buildings (Kreiss, 1989), the World Health Organization (WHO) estimated the number of buildings plagued by poor indoor air quality to be as high as 50% and to affect 25% to 40% of all employed persons in the United States. Studies such as these show how IAQ problems can become public health issues. Common descriptive names for this public health issue are Sick Building Syndrome (SBS), Tight

Building Syndrome (TBS), Building Associated Illness (BAI), and Building Related Illness (BRI). Some researchers divide cases into two categories (SBS and BRI), depending on the symptoms that are manifested (Besch, 1989). Nearly everyone, however, accepts the term "Indoor Air Quality." We prefer this latter term because it is descriptive of all types of nonindustrial building problems, and it implies a proactive approach to their solutions.

Regulations and Standards

Neither the Occupational Safety and Health Administration (OSHA) nor the USAF has published regulations concerning IAQ. OSHA published a notice of proposed rulemaking for an IAQ standard on 5 April 1994 (59 Federal Register, 1994). However, OSHA was overwhelmed by over 100,000 comments when the comment period closed in August 1995. Hearings began 20 September 1994 and ran until 13 March 1995, with more than 400 witnesses testifying. The controversy created by the response to the proposed rule, combined with a non-supportive political climate in Congress, effectively halted further action by OSHA.

A number of federal agencies, such as the Department of Energy (DOE) and the Consumer Product Safety Commission (CPSC), are actively involved in IAQ research or policy guidance, but no one agency has a clear regulatory role (Besch, 1989). The federal agencies most active in IAQ issues are the National Institute of Occupational Safety and Health (NIOSH) and the Environmental Protection Agency (EPA), both of which publish guidance, case studies, and summaries of their findings (DHHS-NIOSH, 1989; EPA, 1991).

The only United States consensus standard on IAQ is from ASHRAE. ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality, makes some important contributions to IAQ investigations, but is most useful as a tool for the HVAC experts. The standard describes procedures for providing acceptable air quality and includes design criteria for HVAC systems. ASHRAE has steadily reworked the standard incorporating comments from outside groups such as the American Industrial Hygiene Association (AIHA). In addition, the standard was placed in "continuous maintenance" status. Continuous maintenance means the standard will be revised piecemeal by scheduled consensus action, instead of being reviewed in it's entirety each time, as was previously done under a "periodic maintenance" approach.

Perhaps the most important contribution from ASHRAE 62-2001 is its definition of <u>acceptable</u> indoor air quality as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction." ASHRAE also has published Standard 55-1992, Thermal Environmental Conditions for Human Occupancy, which describes thermal conditions acceptable to 80% or more of typical office workers.

Several international organizations have published standards or guidelines for IAQ. These organizations include the World Health Organization (WHO), the Nordic Committee on Building Regulations (NKB), the Swedish Council for Building Research (Johnson et al., 1991; Berglund and Lindvall, 1991), and the Ontario Ministry of Labour (MOL) (Rajhans, 1989). These standards primarily set concentration limits for air contaminants, with values similar to the U.S. EPA National Ambient Air Quality Standards (NAAQS). The most recent and comprehensive international standard is NKB Publication 61E, Indoor Climate - Air Quality (NKB, 1991), which discusses ventilation systems in detail.

Currently there are two issues regarding standards that are hotly debated among IAQ researchers. The first issue concerns the purpose behind regulating indoor air. Many researchers, such as Fanger (1991), believe indoor air should be regulated to satisfy both health and comfort requirements. Others such as Sundell (1991) emphatically state that improvement of health should be the primary/only concern of IAQ regulation. Sundell cites health deterioration of epidemic proportions to illustrate his concern, such as the doubling of asthma and allergic rhinitis cases in Scandinavia over the course of only 10 years. In our opinion, both health and comfort requirements should be considered in resolving IAQ complaints. Health concerns should receive emphasis because every worker has a right to a healthy work environment, yet comfort concerns (such as drowsiness or cold temperatures) should also be stressed for productivity and morale reasons.

The second controversial issue concerns setting chemical exposure limits for office work. ASHRAE (2001) recommends using one-tenth of the Threshold Limit Values (TLVs) of the American Conference of Governmental Industrial Hygienists (ACGIH, 2001) as standards for nonindustrial workers. On the other hand, both the MOL and the NKB state that occupational standards or fractions of them are not relevant in nonindustrial settings. The ACGIH agrees with the latter assessment and so do we.

Medical Implications

Symptoms of poor IAQ can vary depending on the problem in a building. However, the typical outbreak of IAQ includes "core" symptoms of lethargy (sleepiness, fatigue); mucous membrane irritation (dry throat, stuffy or running nose); headache; eye irritation (dry, itchy, watery, inability to wear contact lenses); and dry, itchy skin or rash (Lyles et al., 1991). Other symptoms encountered may be frequent coughing or sneezing, dizziness, nausea, persistent colds or sinus congestion, chest tightness or difficulty breathing, difficulty concentrating, flu-like symptoms, and an unusual taste or odor (Jones, 1990; Burge and Hoyer, 1990). In addition, some specific diseases have been linked to building occupancy, such as hypersensitivity pneumonitis, humidifier fever, allergic asthma, and allergic rhinitis (Burge and Hoyer, 1990).

Jones (1990) theorizes that there are at least two sub-syndromes of IAQ. The first sub-syndrome predominant in new buildings is probably caused by a chemical source. Described symptoms may be dry, irritated eyes, nose, and throat; fatigue; headache; and sometimes nausea or dizziness. The second sub-syndrome (probably caused by bioaerosols) is predominant in older buildings. This condition consists of symptoms such as itchy skin, itchy watery eyes, congestion and or runny nose. Occasionally, some individuals can have wheezing, chest tightness or general flu-like symptoms. This theory is bolstered by Anderson (1991) who reports that chemicals such as volatile organic compounds (VOCs) affect the neurological centers of the brain giving rise to fatigue, irritation of the eyes and airway, and increased heart and breathing rates.

Lyles et al. (1991) define an IAQ or SBS problem with two requirements: (1) there must be excessive reporting of one or more of the above symptoms by building occupants, and (2) the symptoms must be related to the work environment. Burge and Hoyer consider "excessive" to mean 20% or more of the building population. Jones describes “work related" as a pattern of increasing severity and/or number of symptoms during the workday followed by rapid improvement and relief of symptoms within a short period after leaving work.

Our Experience

The Health and Safety Division (RSH) at the AFIERA conducted IAQ surveys of 60 government office buildings during the period of 1985 to 2002. The buildings surveyed were by request, because of an unsolved IAQ question. These buildings were located in every region of the United States. Worker populations ranged from 10 to over 2,000 people. The year of construction for the buildings was roughly split evenly among the five decades from the 1940s to the 1980s. One-half of the buildings were used for the same purpose as originally designed with only minor modifications. The other half were substantially modified or converted from a warehouse, mainframe computer center, or light industrial complex. A no-smoking policy existed in more than 80% of the buildings (100% since 1993).

In a pamphlet by NIOSH (1989), building air quality problems were categorized by origin of the source of the problem. NIOSH listed only one major problem source per building. The categories of problems NIOSH recognized are inadequate ventilation (52%), chemical contamination (17%), outside contamination (11%), microbial contamination (5%), building fabric contamination (3%), and unknown sources (12%). Our experience is largely in agreement with that of NIOSH, except that we have been able to identify at least one major problem source in 100% of the buildings compared to an 88% rate by NIOSH, and we have encountered microbial contamination in nearly 47% of the buildings compared to a 5% rate by NIOSH.

Table 2, below summarizes our findings of the major causes of IAQ problems in the buildings we surveyed. The collection of observations and air sampling data show the three most frequent sources of unacceptable IAQ are: inadequate design and maintenance of air handlers, shortage of fresh air intake, and low relative humidity. Rates of occurrence shown in the table indicate that we usually find more than one major problem source in a building.

Table 2. AFIERA/RSH IAQ Experience With 60 Office Buildings

Cause		Selected Sub causes	Selected Substrates	Overall Rate
A.	Inadequate Design or Maintenance of HVAC			73% (**44**/60)
		Al. Mold	34% (15/**44**)	25% (15/60)
		A2. Temp Control	45% (20/**44**)	33% (20/60)
B.	Insufficient Fresh Air			55% (33/60)
C.	Low Relative Humidity			33% (20/60)
D.	Poor Housekeeping/ Chemical Source in Work Space			33% (20/60)
E.	Contamination Source in Air Handler			25% (**15**/60)
		E1. Insulation	47% (7/**15**)	12% (7/60)
F.	Poor Circulation in Work Space			18% (11/60)
G.	Mold Sources in Work Space			18% (11/60)
H.	Smoking			12% (7/60)
I.	Stress/Poor Management			15% (9/60)

FACTORS INFLUENCING INDOOR AIR QUALITY

There are many theories about the causes of IAQ-related symptoms. The causes most implicated in the literature include comfort parameters such as carbon dioxide (CO_2) concentration, relative humidity, temperature, and occupant density; contaminants such as biological aerosols, dust and fibers, VOCs, tobacco smoke, combustion products, ozone, pesticides, asbestos, and radon; and problems with the operation or maintenance of the ventilation system (Burge and Hoyer, 1990). Each of these causes will be discussed in more detail later.

Carbon Dioxide and Fresh Air

In our experience, CO_2 concentration is a useful indicator of inadequate make-up (fresh) air. We also believe that concentrations above 600 parts per million (ppm) may <u>cause</u> specific IAQ irritations and symptoms. There exist excellent correlations to high CO2 levels and symptom intensity and the number of affected individuals. In our experience, between 15% and 33% of the population will have symptoms when the level is between 600 and 800 ppm. Roughly one-third to one-half become symptomatic between 800 and 1,000 ppm, and virtually everyone will have some or all previously mentioned symptoms when the CO_2 level is greater than 1,500 ppm.

ASHRAE 62-2001 states, comfort (odor) criteria are likely to be satisfied if the ventilation rate is set so that indoor CO_2 concentrations do not exceed 700 ppm above outdoor air concentrations. Outdoor air concentrations of CO_2 are typically 300-400 ppm. Other organizations that also recommend 1,000 ppm CO_2 are the Swedish Council for Building Research (Johnson et al., 1991), the Ontario MOL, the WHO, and the Japanese government (Rajhans, 1989). Some researchers recommend lower limits. Quinlan et al. (1989) recommends a limit of 800 ppm, and Rajhans (1983) and Strindehag et al. (1990) recommend a limit of 600 ppm.

It is important to note that the ventilation rate should not be based solely on CO_2 levels. Limiting the indoor CO_2 level to 700 ppm above the outdoor concentration, through dilution or treatment does not assure acceptable indoor air quality and does not meet the requirements of ASHRAE Standard 62. At concentrations typically found in buildings, CO_2 is not considered harmful. CO_2 is a "tracer gas" used to indicate the amount of people-generated contaminants (odors) in the space, but it does not reflect concentrations of other contaminants, such as those generated within the building (VOCs) or those brought in from outdoors (American Standard 2002).

It remains imperative to fully understand the basis for a consensus acceptable level of CO_2 within a building. ASHRAE 62-2001 points out that a CO_2 concentration of 700 ppm above outdoor air is **not** considered a health risk. Many IAQ researchers unfortunately interpret "no health risk" to mean the same as "no physiological effect," and waste their resources looking for a mystery contaminant that is causing discomfort in workers. On the contrary, Pritchard (1976) reports that the human body is very sensitive to the incoming concentration of CO_2. Slight changes from the ambient concentration of 300-400 ppm will cause a compensatory increase in the breathing rate. Burge and Hoyer (1990) report that headache, drowsiness, difficulty concentrating, and dizziness are associated with elevated concentrations of CO_2. Rajhans (1983) adds eye irritation, a sensation of stuffy or stale air, and fatigue to this list. Wallingford (1986) reports that one should expect occasional complaints at CO_2 concentrations of 600 to 800 ppm, more complaints at 800 to 1,000 ppm, and general complaining above 1,000 ppm.

To show the correlation between CO_2 concentration and specific complaints, we modeled human response to CO_2 by assuming there is a "no-effect" concentration of CO_2 where all persons are satisfied. We also assumed the concentration of CO_2 cannot rise high enough to dissatisfy everyone.

CO_2 concentrations were correlated with percentage satisfaction, based on complaints of fatigue, drowsiness, lack of concentration, and sensations of breathing difficulty (items 9 to 12 from the Historical Questionnaire in Appendix F). "Dissatisfaction" is defined by a response of 2 (often) or 3 (always) on at least one of those four items. Figure 1 shows a log-linear regression line of data from medical interviews and questionnaires performed in 18 buildings. Stratification of CO_2 concentration in some buildings allowed us to have more than one data point per building.

The equation of the regression line in the figure is:

$$S_C = 100 \times \exp[-0.0015 \times (C_s - 435)]$$

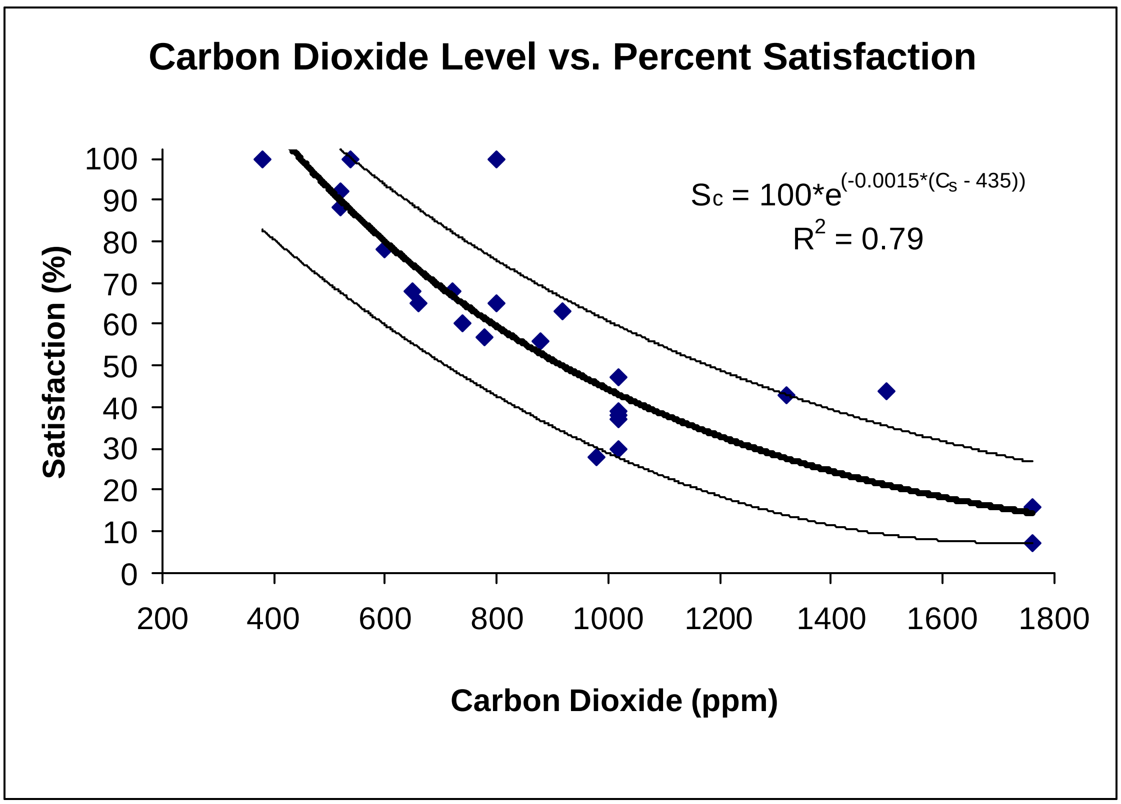
Where: S_c = satisfaction rate (%),

And: C_s = steady state CO_2 concentration in the work space (ppm).

The correlation coefficient, r^2, is 0.79.

An 80% satisfaction rate or better requires CO_2 concentrations below 580 ppm according to the model, which we round to 600 ppm. When C_s is 1,000 ppm, a 42% satisfaction rate is predicted.

Figure 1. Rate of satisfaction of building environment based on physiological effects of carbon dioxide.



Workers are the only significant source of CO_2 in an office environment, so it is fairly simple to relate CO_2 concentration to flow of fresh air using tracer gas theory.
Using the steady state CO_2 concentration, the relation is:

$$Q = \frac{11{,}500\ n}{C_s - C_a}$$

Where: Q = fresh air flow rate (cubic feet per minute, cfm),

n = the number of persons served by the air handler,

C_s = steady state CO_2 concentration in the work space (ppm),

C_a = the concentration of CO_2 in the ambient (outdoor) air (ppm),

And: 11,500 is a constant based on the average human CO_2 generation rate of 0.0115 cfm per office-worker. This constant comes from ASHRAE 62-2001, which assumes a breathing rate of 9 liters of air per minute and a concentration of CO_2 in the expired breath of 37,000 ppm.

We have verified this equation in several buildings. We use this equation to calculate the fresh airflow required per person to keep the CO_2 concentration at 600 ppm or below. The average outdoor concentration of CO_2 we find on surveys is 325 ppm. Thus, $Q/n = 11{,}500/(600-325) =$ 42 cfm/person.

Using a similar equation, ASHRAE (2001) recommends that a minimum of 20 cfm/person of fresh air be provided in office settings to achieve 1,000 ppm CO_2 or lower. A building designed to just meet the minimum fresh airflow recommendations of ASHRAE (2001) is an excellent candidate for CO_2 related complaints.

Only one other organization makes fresh air flow recommendations substantially different from ASHRAE. The Swedish Allergy Commission recommends a fresh airflow of 30 cfm/person for buildings with average emissions and 60 cfm/person in buildings with high emissions (Johnson et al., 1991).

A simple method of guaranteeing enough fresh air to a work space is to measure and control the carbon dioxide level in the return (exhaust) air chamber of the HVAC air handler. At least two companies have begun marketing carbon dioxide control systems.

In summary, our experience indicates that 1000 ppm CO_2 can be too high to satisfy 80% of the population, as ASHRAE asserts. Our observations show that CO_2 has physiological effects at levels above 600 ppm, which can lead to discomfort and dissatisfaction with the environment. A goal for IAQ would be that the CO_2 concentrations not exceed 600 ppm and that a minimum of 40 cfm/person of fresh air be provided to satisfy this requirement. However, depending on the outdoor climate this can be a difficult standard to achieve.

Relative Humidity

Relative humidity below 40% can cause specific physiological effects that lead to discomfort and dissatisfaction with the environment. Symptoms include dry, sore nose and throat, bleeding nose, sinus and throat irritation, dry scratchy eyes, inability to wear contact lenses, and dry itchy flaking skin. The number of persons affected increases as the relative humidity decreases below 40%. Quinlan et al. (1989) and Lyles et al. (1991) report similar symptoms.

The inability to wear contact lenses in a building with low relative humidity results from fluid loss from the exposed outer eye surface (conjunctiva, cornea, and sclera) to the dry indoor atmosphere. The resultant loss of ocular fluid/lubrication causes an irritative inflammation to the exposed eye and may enhance the possibility of an infection. Even without contact lenses the eyes can feel dry, irritated, and itchy.

Low relative humidity also contributes to an increase in respiratory illness by weakening the defenses provided by the pulmonary mucous membranes. There are many examples in the scientific literature that support the increased opportunity for human respiratory infections with long term/frequent exposure to buildings with low relative humidity (Kreiss, 1989; Brundage et al., 1988; Mosher, 1987; Morey and Woods, 1987). A significant side effect of respiratory illness that often signals a low humidity problem is frequent headaches from sinus congestion and inflammation.

To model human response to low relative humidity, we used the same technique as used for CO_2 earlier. We assume there is a "no-effect" relative humidity where all persons are satisfied, but there is no relative humidity so low that all persons are dissatisfied. Again, we use an equation of the exponential form.

We correlated relative humidity measurements with percentage satisfaction, based on complaints of nasal congestion/problems, sinusitis, eye irritation and itching, dry and itchy skin, and headaches (items 2, 5, 7 and 8 on the Historical Questionnaire in Appendix F). "Dissatisfaction" is defined by a response of 2 (often) or 3 (always) on at least one of those four items. Figure 2 shows a log-linear regression line of data from medical interviews and questionnaires performed in 20 buildings. (Stratification of relative humidity in some buildings allowed us to have more than one data point per building.)

The equation of the regression line in the figure is:

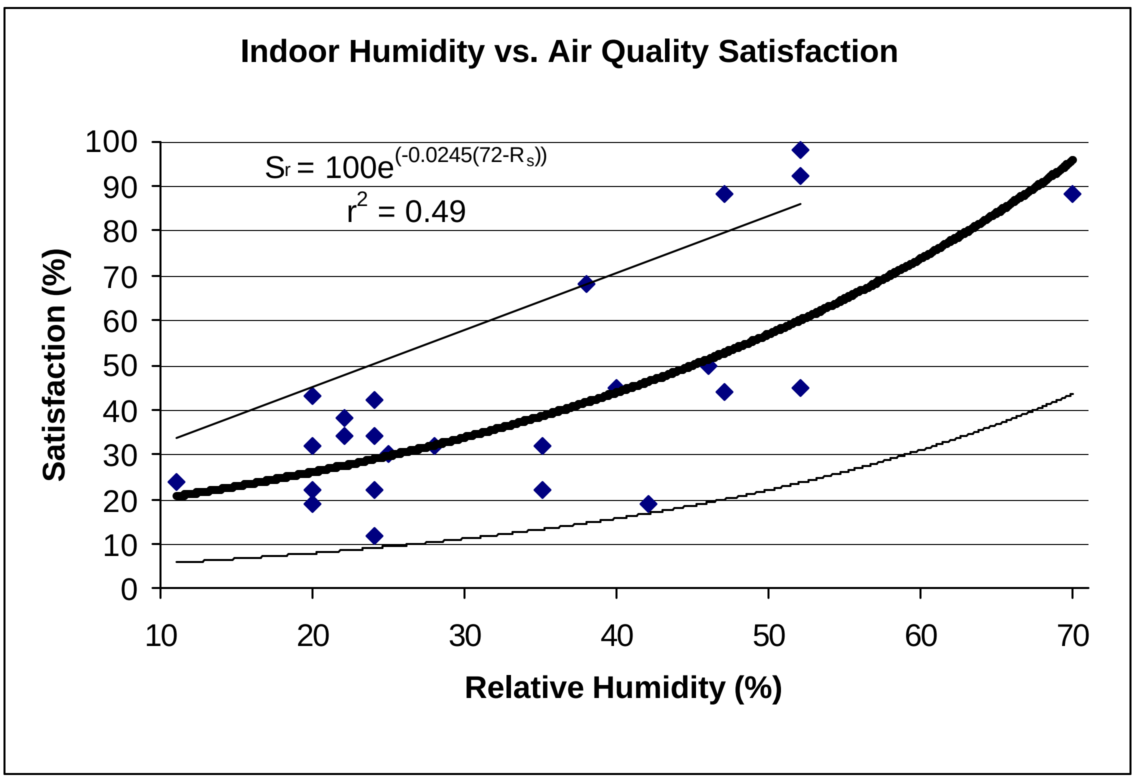
$$S_r = 100 \text{ x } \exp[-0.0245\,(72 - R_s)]$$

Where: S_r = satisfaction rate (%),

And: R_s = work space relative humidity (% RH).

The correlation coefficient, r^2 is 0.49. The 90% confidence limits are drawn in the figure. The correlation is weak, but we believe this is because HVAC systems do not control humidity. In other words, while the questionnaire responses are based on the prevailing humidity in a building, the relative humidity we measured on a particular day may not have been indicative of the prevailing humidity.

Figure 2. Rate of satisfaction of building environment based physiological effects of relative humidity.



An 80% satisfaction rate or better is predicted by the equation when the relative humidity is above 63%. While the data shown is not convincing enough to flatly recommend a relative humidity of 63%, relative humidity below 40% cause strong dissatisfaction with the environment.

At the other end of the spectrum, we have found relative humidity above 65% cause other problems. Carpets, curtains, furniture, etc. can absorb enough moisture at 65% relative humidity to promote microbial growth. Therefore we recommend controlling the relative humidity in an office in the 40% to 60% range.

ASHRAE 55-1992 recommends for thermal comfort that the dew point be kept between 35^{o} F and 62^{o} F, which is the equivalent of 30% to 60% relative humidity at their recommended operative temperatures. ASHRAE 62-2001 also states that relative humidity from 30% to 60% is acceptable for office environments. It warns against high humidity (above 70%) since fungal contamination begins to appear at this moisture level. Johnson et al. (1991) report that VOCs are emitted at greater rates in humidity above 70%.

In summary, we recommend a relative humidity of 50% $\pm$ 10% and the installation of humidity control systems to meet this requirement when necessary. We believe it is important to have humidity control devices in HVAC systems since the range of acceptable humidity (40% to 60%) is narrow and in most parts of the country, "natural" humidification does not keep a building within this range all year. If the humidity is consistently below 40%, one can expect complaints of dry itchy skin, irritated eyes, nose and throat, sinus congestion, and headaches. If the humidity is consistently above 70%, one can expect mold growth and allergic symptoms.

Temperature

In our experience, office workers are tolerant of dry bulb temperatures between 20^{o}C (68^{o}F) and 24.4^{o}C (76^{o}F). HVAC systems are designed to control temperatures within this range, and most do a good job on the average. However, we often find parts of a building with wide temperature variations over short periods of time, such as cold blasts of air coming out of supply air diffusers. Temperature variations in an indoor work environment can cause significant worker dissatisfaction. We have performed surveys where approximately 50% of the workers complain of being too cold, and the other half complain of being too hot.

We also find significant temperature dissatisfaction among workers in buildings where thermostats are nonexistent or "tamper-proofed," even if the air temperature is reasonably satisfactory. Denying temperature control to workers can have great effects on morale. Some companies have realized this and have begun marketing individual control systems which give each worker dials on his desk to moderate local heating and cooling. While we don't necessarily recommend such systems, we stress that giving workers some control over their environment can help boost morale.

ASHRAE 55-1992 offers the most comprehensive picture of thermal comfort. ASHRAE uses "operative temperature" in setting its limits. The operative temperature takes into account radiant temperature sources and is approximately equal to the average of the dry bulb temperature and the radiant temperature when the air speed is less than 0.4 meters per second (m/s) [80 feet per minute (fpm)] and the radiant temperature is less than 50^{o}C (120^{o} F). This operative temperature applies to most office buildings. ASHRAE recommends cooling season

operative temperatures of 23^{o}C to 26^{o}C (73 to 79^{o}F) and heating season operative temperatures of 20^{o}C to 23.5^{o}C (68 to 75^{o}F) in offices. The difference in seasons occurs because ASHRAE assumes persons in the winter will be wearing more clothing, such as sweaters and heavier pants. Thus, "summer" and "winter" settings should depend locally on what people ordinarily wear to work, not strictly on the calendar definitions of summer and winter.
Other factors reported in ASHRAE 55-1992 that affect human perception of "too hot" or "too cold" are: high radiant temperatures, fluctuations in temperature of more than 2.2^{o}K (4^{o}F) per hour, air movement greater than 0.25 m/s (50 fpm) in the work space, a temperature difference from foot to head of more than 3^{o}K (5^{o}F), and radiant asymmetry from any direction (above, below, sideways) caused by a very warm or very cold surface, such as a radiator or window. Johnson et al. (1991) report that the effects of high temperatures are headache, fatigue or lethargy, and a sensation of dry air. They report the effects of cold temperatures are clumsiness and complaints of draftiness and being chilly.

In summary, temperatures outside of the comfort range described by ASHRAE and conditions of high airflow, high radiant heat, or large changes in temperature can lead to significant complaints of being too hot or too cold. Giving workers some control over temperature (e.g., via access to thermostats) can help improve morale.

Occupant Density

We have found that giving workers enough space is essential to their comfort and morale. CO_2 concentrations, odor, and relative humidity will increase with occupant density (Morey and Shattuck, 1989). In addition, as the occupant density increases, the heat load from people and their office equipment can increase beyond the cooling capacity of the air conditioning system.

Air Force Handbook 32-1084, Facility Requirements (1996) provides criteria for two types of office areas. For administrative areas with private offices and/or using traditional furniture, the building gross floor area is 162 ft^2/person, the building net floor area is 130 ft^2/person, and the net office area is 90 ft^2/person. For administrative areas using prewired workstations, systems furniture, or ADP furniture, the building gross floor area is 135 ft^2/person, the building net floor area is 108 ft^2/person, and the net office area is 68 ft^2/person. Building gross floor area takes into account additional space required for fixed walls, mechanical space, etc.

ASHRAE 62-2001 assumes offices will have a minimum of "140 ft^2/person." State and local building codes generally state a minimum of "100 ft^2/person," but most commercial office buildings actually provide over "200 ft^2/person" (Offermann and Gilbertson, 1991). Occupant densities should be determined for rooms that look crowded and not as an average for a whole building.

Bioaerosols

The usual bioaerosols implicated in building-related health effects are fungi and bacteria. Normal buildings contain bacteria and fungi. The concentration of fungi and bacteria in buildings is related to the concentration of the microorganisms in the outdoor air, which is typically the source of indoor microorganisms.

It is important to remember that fungi and bacteria in buildings are normal and only become a problem when indoor amplification occurs. Indoor growth of fungi and bacteria is always caused by water intrusion through the roof, walls, or floors, or as a result of high humidity. Fungi and bacteria usually occur in the indoor air in concentrations equal to about 20% of that found in the outdoor air. Amplification is indicated when the indoor concentration is higher than that found in the outdoor air. Since the indoor concentration is related to the concentration in the outdoor air, there is no specific concentration of indoor fungi and environmental bacteria that is acceptable or unacceptable. ACGIH does not support any existing numerical criteria for interpreting data on biological agents from source or air samples in non-manufacturing work environments. ACGIH (1999) recommends gathering the best data possible and using knowledge, experience, expert opinion, logic, and common sense to interpret information and design control and remediation strategies.

There are no standards regulating microorganisms in the environment (Burge and Hoyer, 1990). Air sampling is difficult, expensive, and usually unnecessary because a contamination site is usually obvious. Water stains, visible mold growth and decayed substrates would be indications of a contamination site that can be visually identified. It often costs more to sample a suspected contamination site than it does to clean it up. According to Burge and Hoyer, "air sampling for bioaerosols is useful only when there is clear medical evidence of hypersensitivity reactions and an obvious source of contaminant is not found." If a decision to sample is made, contact the AFIERA Industrial Hygiene Branch. We can assist you with establishing a sampling plan and getting your samples processed. If medical personnel request sampling, it should be discussed with your base Flight Medicine/Occupational Health specialist. If none is available please contact the Occupational Health physician at AFIERA. Appendix D contains a protocol for bioaerosol sampling, if the decision to sample is made.

Fungi: Exposure to airborne fungal matter can cause the following effects on human health:

- Irritation: Symptoms are usually associated with the eyes, nose, throat, and skin. Though not often serious, these symptoms can be persistent and annoying, frequently leading to disruption, and loss of worker efficiency.

- Infections: Fungi are not a frequent cause of infections but when they occur, they can be serious and difficult to treat. These can vary from superficial skin diseases (e.g., athlete's foot) to serious lung infections, or even invasive disease throughout the body. Environmental fungi commonly found in buildings are very unlikely to cause infections. Two species of infectious fungi are of particular concern. These are Histoplasma Capsulatum Var. Capsulatum and Cryptococcus Neoformans. Both cause pulmonary infections by inhalation of airborne spores, and are associated with bird or bat droppings.

- Allergies: Allergic reactions are far more common than infections and individuals may be allergic to several different fungi. Up to 20% of the U.S. population may suffer from allergic rhinitis. A more serious allergic problem is asthma, which affects 3-5% of the population. Asthma attacks can be triggered by a variety of environmental factors including fungi.
- Mycotoxins and toxic effects: It has been known for several decades that many fungi produce a variety of mycotoxins that are detrimental to other microorganisms as well as humans and animals. It is well documented that these mycotoxins are dangerous when ingested as moldy food or feed (e.g. aflatoxin in damp nuts and grain contaminated with Aspergillus Flavus.) Currently, a highly controversial relationship is being suggested between mycotoxins produced in fungal spores and toxic effects resulting from exposure to fungal bioaerosols in indoor environments. Review panels organized by the Centers for Disease Control and Prevention and the AIHA Indoor Environmental Quality Committee have concluded that there is not enough evidence to support an association between mycotoxin production in fungi and building associated diseases (PathCon 2000.)

Bacteria: Bacteria in the indoor environment can usually be categorized into one of three groups: human-commensal bacteria, environmental bacteria, and thermophilic bacteria.

- The human-commensal bacteria are those such as Staphylococcus, Micrococcus, Streptococcus, Moraxella, Stomatococcus and Escherichia coli that commonly grow in harmony with humans and usually do not persist permanently in the environment. When found in the indoor environment, their most likely origin is the building occupants. Their growth is not usually associated with the building environment other than high occupant density or poor ventilation.

- The environmental bacteria are those such as Pseudomonas, Acinetobacter, Aeromonas, Arthrobacter, Bacillus and Sphingomonas. When high concentrations of these are found in the indoor environment, their most likely sources are through the outdoor air source or growth in a wet indoor environment. These are unlikely to be from human sources. Growth of these bacteria frequently occur in water damaged or flooded buildings. Heavy growth may occur very quickly, within one or two days causing odors and health complaints. The gram-negative bacteria, which are very commonly found in water-damaged buildings, may contain endotoxin as a component of their cell walls. When they undergo decomposition and become aerosolized, they may cause an upper respiratory, mild flu-like disease.

- Thermophilic bacteria are those that grow at high temperatures (50-56 degrees C). These are more likely to be an agricultural problem rather than from an indoor building environment. They may be associated with compost heaps, moldy hay and other sources of organic matter undergoing decomposition. They can occur in water-damaged buildings on rare occasions. Long-term exposure may cause hypersensitivity pneumonitis.

Sampling Strategies for Bacteria and Fungi

Two general sources of samples may be useful for detecting amplification of bacteria and fungi in the indoor environments.

Bulk and surface samples: Bulk samples (e.g. wall board, carpeting, ceiling tiles, and insulation) may provide useful indications of the type and amount of bacterial and fungal growth occurring in the indoor environment. Surface samples collected using cotton-tipped swabs or sterile gauze may also be useful for areas where the building material cannot be collected. The presence of low concentrations of bacteria and fungi on indoor building materials is normal. "Extensive" visible fungal growth has been defined as surface areas greater than 3 m^2 (NYCDH, 1993.) Extensive contamination should be avoided and any contamination that exists should be removed and further contamination prevented (ACGIH 1999.)

Air samples: These are the most accurate indication of exposure to a microbial hazard. However, a negative finding does not prove the absence of the hazard, but indicates only that the hazard was not detected. There are no specific number of bacteria and fungi in the indoor environment that is acceptable or unacceptable. The indoor concentration must be evaluated comparing it to the outdoor concentration. Generally, a minimum of three locations in a building should be sampled: an indoor complaint site, an indoor noncomplaint site and an outdoor site. The locations should be sampled on at least two occasions, thus an investigation will involve a minimum of six samples.

The samples should be collected directly onto a medium for culturing bacteria and fungi. Therefore, at least two types of medium are required. The air samples must be collected with a calibrated air sampler (e.g., Andersen N6 air sampler) for a measured length of time in order to report the findings as cfu/m^3.

Special Bacterial Groups

There are two special bacterial groups that will not be detected by the usual microbiology laboratory conducting the usual culture test for bacteria. These are Legionella bacteria and Mycobacterium and both of them require special and specific laboratory analyses to detect them.

Legionella: These bacteria occur naturally in rivers, lakes, and streams. They only become a problem when amplified in warm (80 to 120 F) building water systems where the water is aerosolized (cooling towers, hot water systems, whirlpool baths, and indoor decorative fountains). Two forms of disease may occur: Legionnaires' disease (pneumonia) and Pontiac fever (non-pneumonic flu-like disease). Implementing treatment methods to prevent amplification and conducting microbiological monitoring to ensure that the treatment method has been effective in controlling the hazard.

Environmental Mycobacteria: Environmental mycobacteria are species of Mycobacterium in the same genus with Mycobacterium tuberculosis, the agent causing tuberculosis. These do not cause tuberculosis and are naturally found in the environment, in contrast to M. tuberculosis, which is only found in association with people. The environmental mycobacteria are very slow growing and may take weeks to culture in the laboratory. The so-called rapid growing mycobacteria (which may take two weeks or more to culture) have been found to grow in metal working fluids (grinding coolants) in industrial plants and have been documented to cause hypersensitivity pneumonitis in machine workers exposed to bioaerosols of the contaminated fluids (Shelton, et al. 1999).

Adverse Health Effects Associated with Mold

The following information is from an evidence-based statement from the American College of Occupational and Environmental Medicine (ACOEM, 2002). Approximately 5% of individuals are predicted to have some allergic airway symptoms from mold over their lifetime. However, it should be remembered that molds are not dominant allergens and that outdoor molds are generally more abundant and important in airway allergic disease than indoor molds. Most fungi are not pathogenic to healthy humans. A very limited number of pathogenic fungi such as Blastomyces, Coccidiodes, Cryptococcus, and Histoplasma infect normal subjects and may cause fatal illness, but these fungi are not normally found in the home or office environment. Cryptococcus are associated with bird droppings, Histoplasma are associated with bat droppings, Coccidiodes is endemic in the soil of the southwest U.S. and Blastomyces are endemic in soil and decaying wood materials of North America. Some species of fungi are known to produce secondary metabolites, or mycotoxins. Serious veterinary and human mycotoxicoses have been documented following ingestion of foods heavily overgrown with mold. In high concentrations, inhalation of these mycotoxins can cause illness. However, documented cases of this type have generally been associated with agricultural settings in which workers have inhaled high concentrations of mixed organic dust. Current scientific evidence does not support the proposition that human health has been adversely affected by inhaled mycotoxins in the home, school or office environment.

Individuals with allergic airway disease should take steps to minimize their exposure to molds and other airborne allergens, such as animal dander, dust mites and pollens. For these individuals, it is prudent to take feasible steps to reduce exposure to aeroallergens and to remediate sources of indoor mold amplification. Sensitized individuals may need to keep windows closed, remove pets, use dust mite covers, use high quality vacuum cleaners, or filter outdoor air intakes to minimize exposure to inhalant allergens. Maintaining humidity levels below 40% can reduce fungal and dust mite growth. However, reducing humidity levels below 40% is not a recommended action for resolving an indoor air quality problem. Humidity levels below 40% can cause symptoms of dry, sore nose and throat, bleeding nose, sinus and throat irritation, dry scratchy eyes, inability to wear contact lenses, and dry itchy flaking skin. When there is indoor amplification of fungi, removal of the fungal source and remediation of the water intrusion that facilitated the mold growth, are key measures to be undertaken so as to decrease the potential for indoor allergen exposure.

Remediation of Microbiological Contamination

AFIERA can assist with remediation efforts by providing general guidance on the principles of microbial contamination assessment and remediation. The lack of regulatory guidance combined with the reality that each situation is unique makes it impossible to use a blanket approach. Each case will have unique characteristics and must be dealt with on a case-by-case basis. The guidance included in this document along with consultation by AFIERA will provide you with the knowledge to oversee a remediation effort. Above all, ensure that a common sense approach is used and the potential hazards are communicated to the building occupants accurately.

When deciding on remediation of microbial contamination, there are two basic courses of action. Aerotech Kalmar Laboratories' IAQ Microbiology Reference Guide (2002) lists the following general provisions for the remediation of microbial contamination. Non-porous surfaces can be cleaned and disinfected. Porous materials must be replaced. Disinfection is not a substitute for removal of porous material, as dead fungi remain allergenic and toxigenic. Because of the health effects associated with elevated concentrations of microorganisms, only competent individuals familiar with the precautionary measures required should perform remediation. There are no specific regulations governing this type of remediation, however, general occupational safety is addressed in two OSHA regulations. The general duty clause of the 1970 OSHA Act requires employers to provide a work environment "free from recognized hazards" and the 1987 Hazard Communication Standard provisions for employers to inform employees of chemical work-place hazards, including carcinogens, sensitizers and neurotoxins. Precautionary measures that may be required include: (1) negative pressurization, (2) physical isolation, (3) the use of respirators equipped with P-100 filters, (4) protective equipment for eyes and skin and (5) the use of asbestos abatement precautions.

The Industrial Hygiene Branch recommends that building occupants be removed from the affected area **only** during the remediation process, unless there are documented illnesses associated with the building. In cases of documented illnesses, an occupational health/aerospace medicine specialist should be consulted prior to removing the individual. If such a specialist is not available contact the occupational medicine physician at AFIERA. An entire building does not have to be evacuated to remediate one office! Prompt removal of contaminated material and infrastructural repair should be the primary response to microbial contamination in buildings.

Emphasis should be placed on preventing contamination through proper building maintenance and prompt repair of water damaged areas. Chronic exposure to airborne microbial contaminants may pose a risk of adverse health effects caused by irritant and allergic reactions.

The simplest and most expedient remediation that properly and safely removes microbial contamination from buildings should be used. This includes prompt removal and/or cleaning of contamination and repair of the defects that led to water accumulation. Widespread contamination poses much larger problems that must be addressed on a case-by-case basis in accordance with published guidelines for remediation. Effective communication with building occupants is an essential component of all remedial efforts. Building occupants will become concerned if they see remediation workers in their building with respirators and other protective equipment. Communicate to them they are safe and honestly answer their questions in a way they can understand.

In summary, water is a great precursor for the development of many bioaerosols that may become a significant health threat in a building environment. Such contamination may cause workers to become ill. Sources of bioaerosols are generally, poorly maintained ventilation systems and porous material that has become water soaked. While we have minimal control over most bioaerosols in the outdoor environment, we still maintain access to the techniques and resources for their identification and measurement in the indoor environment. However, our ultimate goal is to prevent or at least minimize their existence in the indoor working environment.

Water/Flood Damage Cleanup

The Industrial Hygiene Branch has consulted on many cases where water damage caused by flooding; rainwater infiltration of the building envelope, or leaking/burst pipes has resulted in IAQ problems. In all cases, problems could have been avoided if proper clean up had been performed. The EPA Fact Sheet, "Flood Cleanup: Avoiding Indoor Air Quality Problems" (1993) discusses problems caused by microbial growth, as well as other potential effects of flooding on long-term indoor air quality and steps that can be taken to lessen these effects. Although the information is aimed at flooding specifically, the same principles apply to any building where water damage has occurred. Listed below is additional guidance published by Aerotech Kalmar Laboratories on water/flood damage cleanup.

The most significant event that precipitates building wide water damage and the subsequent environmental hazards associated with microbiological contamination is some type of flooding episode, whether it be from heavy rains, a broken water line or other catastrophic event. Fortunately, proper techniques following a water damage event can eliminate or significantly reduce microbial damage.

Rapid response is critical. A restoration or remediation company should be on site within hours of a flooding episode. The restoration company must also have the proper equipment to perform the task quickly and efficiently, including water extraction and dehumidification equipment. At a minimum the restoration company should:

1. Remove carpet and pad.

2. Remove cove moldings or other moldings if water has entered wall cavity

3. Drill holes in wallboard to facilitate drying inside wall cavity.

4. Pay special attention to built in cabinets, remove kick plates or drill holes.

5. Have special equipment for remediation of microbiological contamination if necessary.

If the damage is by anything other than clean water (potable water) special precautions must be taken. In sewage situations, pathogenic bacteria and viruses must be dealt with by evacuation of occupants, until cleanup and disinfection has been completed. Workers entering the contaminated area must wear protective clothing and respirators.

Microbiological contamination is a concern if cleanup and drying is not accomplished expediently. Clean water floods that are not dried out rapidly will require extensive demolition and removal of porous materials. A microbiologically damaged structure should be remediated as soon as possible. Occupants of the structure should be removed from the contaminated areas **only** during the remediation process or if there are documented illnesses associated with the building. Every situation is unique and common sense should be applied to all cases. As a general rule of thumb the remediation company should:

1. Equip remediation workers with protective equipment.

2. Contain the area in need of remediation.

3. Exercise extreme care when removing contaminated materials and bag them before removing them from the contaminated area.

4. Remove contaminated or water damaged porous organic materials and discard.

    a. Drywall, ceiling material, insulation.

    b. Flooring, carpet, pad, sub floor material, cabinets with particleboard bases.

5. Remove spores and other fungal particulates from the air and from surfaces using HEPA rated filters and vacuums.

6. Use negative air containment to protect other parts of the structure during demolition.

7. Use HEPA filters to clear the air after demolition.

Treatment of contaminated porous materials with biocides is not effective. Biocides inhibit growth, but most are not sporicidal. Nonviable fungi remain allergenic and toxigenic.

Dust and Fibers

When dust or fiber concentrations are high and humidity low, we have found enhanced skin problems. The skin dries when the humidity is low. This dryness decreases its resistance to irritating effects. We have surveyed an office where fiberglass fibers caused such an irritating rash that workers were certain the office was infested with fleas. Burge and Hoyer (1990) also report that fiberglass can cause epidemics of rash and itching. If video display terminals (VDTs) or other sources of static electricity are present, irritation of the skin (particularly of the face around the eyes) often occurs. The VDT attracting dust particles and later propelling them outward to the operator can cause irritation.

The NKB (1991) reports that typical outdoor dust levels are between 5 and 30 micrograms per cubic meter ($\mu g/m^3$). They report that dust levels inside buildings typically run about 100 to 200 $\mu g/m^3$. It is noteworthy that the EPA has established National Ambient Air Quality Standards (NAAQS) for total particulate matter in outdoor air of 150 $\mu g/m^3$ over any 24-hour period and 50 $\mu g/m^3$ as an annual average. Poor housekeeping sometimes is the cause of high dust levels, but dust and fibers build up in an office building primarily through the ventilation system. More often than not, the air filters we find in air handlers have less than 20% capture efficiency. Thus, dust from the outdoors is allowed to enter and collect in the system. Also, the current trend in air handlers is to line the inside of ductwork with fiberglass insulation rather than wrap it around the outside. After just a few years, the interior insulation deteriorates and releases fibers into the air. HVAC maintenance crews rarely give a second thought to removing or replacing damaged insulation.

Recently, there have been stories in the media that fiberglass is as carcinogenic as asbestos, or worse. From our knowledge of the aerosol behaviors of asbestos and fiberglass, fiberglass does not break into the same size and shape of fibers as asbestos, and therefore, is not a cancer-causing hazard. It is however, a severe irritant to the skin and can cause respiratory irritation if inhaled in high enough concentrations.

In summary, high concentrations of dust and fibers cause skin and respiratory system irritation. The most common reasons for high concentrations are low efficiency particulate filters and deteriorating fiberglass insulation in the air handler.

Volatile Organic Compounds

Volatile organic compounds (VOCs) have been widely implicated as a primary source of irritation in office buildings, with formaldehyde the compound of most concern (Burge and Hoyer, 1990). Other VOCs commonly found in the workplace are heavy alkanes (7 to 11 carbons in a hydrocarbon chain), aromatics (toluene, xylene, ethylbenzene), and cyclic compounds (cyclohexanol, butylcyclohexane) (Lyles et al., 1991). The NKB reports the range of VOC concentrations measured in offices have been from 0.05 to 1.3 milligram per cubic meter (mg/m^3), compared to outdoor levels of 0.01 to 0.04 mg/m^3. Higher concentrations of VOCs will exist in new buildings or in buildings with new furniture or paint. Such levels will dissipate within a few weeks unless the air is highly recirculated.

Quinlan et al. (1989) report the symptoms of low-level formaldehyde concentrations to be headache and irritation of the eyes, nose, and throat. Irritation for many people begins at about 0.1 ppm. Molhave et al. (1986) conclude that persons exposed to low concentrations of VOCs are likely to complain of eye and mucous membrane irritation, an unpleasant odor, a sensation of temperature increase, and difficulty concentrating. The concentrations Molhave et al. studied were 5 mg/m^3 and 25 mg/m^3, or 4 to 100 times the typical concentrations found in offices by the NKB. No one has done a rigorous study of VOC effects at levels below 1 mg/m^3. Other reported symptoms of elevated VOC concentrations are headache, nausea, dizziness, fatigue or lethargy, and respiratory irritation (Quinlan et al., 1989; Lyles et al., 1991; Anderson, 1991). The chronic effects of low-level exposures of VOCs are unknown (Burge and Moyer, 1990). The symptoms associated with VOC concentrations above 5 mg/m^3 are nearly indistinguishable from symptoms associated with elevated CO_2 concentrations and low relative humidity. In addition, each of the three agents shares a common cause (i.e., high recirculation and little or no fresh air). Therefore, it can be difficult to sort out whether the VOCs or the combination of high CO_2 and low relative humidity is causing problems.

If you feel that high VOC levels may be a problem in your building, formaldehyde sampling can be accomplished by hanging 3M 3721 passive dosimeters in the area for a couple days. There is yet to be a standard method for evaluating "total VOCs" since there are so many compounds present in low concentrations. One method uses a combination of gas chromatography and mass spectrometry to quantitatively identify each component. A less rigorous, but much less expensive, method is to use gas chromatography and flame ionization detection calibrated with a typical VOC such as toluene (Molhave et al., 1986).

In buildings with high levels of VOCs, Burge and Hoyer and others have advocated "baking out" the VOCS by raising the temperature above 26.6°C (80°F) for a week to a month during unoccupied periods. However, Offermann and Gilbertson (1991) have found baking out not to be that successful, and it tends to put cracks near windows and to damage the furnishings. Offermann and Gilbertson recommend ventilating the building with 100% outdoor air instead, for at least a week.

Smoking

There have been many cases recently involving secondhand smoke and the effects it has on building occupants. NIOSH released an 18-page document in July 1991 titled "Current Intelligence Bulletin No. 54, Environmental Tobacco Smoke in the Workplace" (1991). This document states that occupants should not be exposed involuntarily to tobacco smoke in the workplace. Their study involved reviewing such research as a 1986 Surgeon General's report documenting a 30% increase in risk of lung cancer in nonsmokers exposed to tobacco smoke. AFI 40-102, Tobacco Use In The Air Force (2002), prohibits smoking (cigar, cigarette, pipe) and the use of smokeless (spit/loose tobacco) products in the workplace to protect the health of all workers. AFI 40-102 makes the following provisions that effect IAQ:

1. The use of tobacco products is permitted only in designated tobacco use areas.

2. The Air Force prohibits indoor tobacco use in all Air Force facilities, except in assigned government housing and recreation facilities designated by the installation commander permitting indoor tobacco use (smoking). In such cases, the tobacco use area is designated and separate from common areas that non-smokers must utilize. The designated indoor tobacco use area may not be public, common-use area, such as: restrooms, hallways, stairways, or offices. Installation commanders are encouraged to limit the size of these areas.

3. Tobacco use is prohibited in recreation facilities offering programs that are oriented toward children. Additionally, tobacco use is prohibited in all other recreation facilities during children's programs.

4. Points of ingress and/or egress (i.e. doors) to facilities, in addition to windows and air intake units/vents, are considered part of the workplace for the purpose of the instruction. Any designated tobacco use areas will be away from these points. Tobacco use area distance must be sufficient so as not to allow smoke to be drawn into the building through openings in doors, windows, and/or air intake units.

AFI 40-102 also addresses smoking in lodging, dormitory, and housing facilities. BEEs and PHOs should refer to the specific provisions of the instruction if complaints about tobacco smoke in these types of facilities are encountered. According to our studies, the smoking ban in the workplace has greatly improved indoor air quality for the military. In our experience, we have found smoking related IAQ problems where outdoor designated tobacco use areas were adjacent to air intake units/vents. This problem is easily remedied by moving the designated tobacco use area. We have also found instances where personnel would smoke in stairways or other secluded indoor areas to avoid going outside in cold (winter) weather. This is clearly a violation of the instruction and individual units must ensure personnel use only designated areas.

Tobacco smoke has been associated with a number of acute responses. Effects include eye irritation, mucous membrane irritation, asthma and hypersensitivity reactions, headache, respiratory irritation, drowsiness, nausea, loss of appetite, an increased rate of respiratory illness, nonallergic rhinitis, and of course an unpleasant odor (Rajhans, 1989; Johnson et al., 1991; Burge and Hoyer, 1990). In addition, the International Agency for Research in Cancer (IARC) has concluded that passive smoke inhalation raises the risk of several forms of cancer (Rajhans, 1989).

Combustion Products

Boilers, fuel burning engines, parking garages, or busy streets near the fresh air intake of an air handler can be a potential source of IAQ complaints (Quinlan et al., 1989). The three likeliest combustion products are carbon monoxide (CO), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). Carbon monoxide is odorless and can cause fatigue or drowsiness, nausea, headache, and difficulty in breathing. The nitrogen and sulfur dioxides have annoying, characteristic odors and cause respiratory system irritation, plus eye and mucous membrane irritations.

When sampling for these combustion products, the most useful standards for comparison are the National Ambient Air Quality Standards (NAAQS) published by the EPA (1997), (annual averages of 0.03 ppm for SO_2 and 0.053 ppm for NO_2, a 24-hour average of 0.14 ppm for SO_2, and an 8-hour average of 9 ppm for CO). Comparison to the current outside concentration is also useful. If there is a problem with combustion products, the solution is to properly ventilate the combustion source or to move the fresh air intake.

Other Contaminants and Contributors

Other contaminants that have been implicated in IAQ surveys are ozone, pesticides, asbestos, lead and radon (Burge and Hoyer, 1990). Although these contaminants are the least likely sources of problems, they are the contaminants most on the minds of building occupants. In addition, poor lighting and poor positioning of VDTs can cause "building-related" complaints not due to the air quality.

Pesticide application will cause short-term irritant effects in some individuals, but if overused or used in a building with high recirculation of air, the irritation can last for months. When overused, pesticides and their inert carriers (often petroleum products) can be absorbed by carpets, wall fabrics, and ceiling tiles, and then will be desorbed back into the air at a later time (Burge and Hoyer, 1990).

Asbestos, lead and radon have only long-term chronic effects, and therefore, are of no concern from an IAQ perspective. However, it is important to educate the workers about the true health effects of these contaminants to alleviate their concerns. Questions about asbestos and lead exposure can be directed to the Industrial Hygiene Branch (AFIERA/RSHI) and questions about radon assessment and mitigation can be directed to the Radiation Services Branch (AFIERA/SDRH).

Insufficient light, glare, and problems with workstation setup (such as an improper angle on the VDT screen or wrong height for the keyboard) can cause eyestrain, headaches, and back pain from poor posture. Often these complaints are incorrectly attributed to the air quality. Questions about improving the ergonomic attributes of an office can be directed to the Health & Safety Division (AFIERA/RSH).

HVAC SYSTEMS

Influence of Ventilation System

The design and maintenance of an HVAC system has primary influence over the air quality inside a building. The HVAC system played a major role in the symptoms experienced by workers in 70% of the buildings we surveyed. In addition, many of the comfort parameters and contaminants discussed earlier can be made worse by the condition of the HVAC system. Dirt, mold and moisture that can accumulate in a poorly maintained HVAC system can contribute to IAQ symptoms. Burge et al. (1987) found that the design features of a building's ventilation system correlate well with the number of IAQ symptoms. Complex HVAC systems require greater maintenance man-hours, and if not provided, can be a contributing factor of poor IAQ. Buildings with many local heating or cooling units were noted to have higher complaint rates than buildings with central heat and cooling.

Unfortunately, an emphasis on energy conservation efforts and budget cutbacks has lead many to forget that the primary function of office buildings is to provide workers with a comfortable and healthy environment in which to work. Providing this environment is largely dependent on the proper design, operation, and maintenance of a building's HVAC system (Morey and Shattuck, 1989). The Ontario Ministry of Labor has concluded that the single most effective solution to IAQ problems is an adequate fresh air supply from a properly designed, operated, and maintained HVAC system (Rajhans, 1989). Moffatt et al. (1991) state that the requirements of proper ventilation should dominate design and construction decisions, not the cost of heating, cooling, or equipment.

Loftness and Hartkopf (1989) list the most notable HVAC failures as: (1) poorly maintained systems, (2) poor or nonfunctioning controls, (3) no fresh air intake, (4) no exhaust, and (5) poor placement or blockage of supply diffusers. Inevitably, these failures occur either because maintenance workers do not have the proper training or someone makes a decision without realizing the impact on the occupants. For instance, ASHRAE 62-2001, Offermann and Gilbertson (1991), and Morey and Shattuck (1989) agree that condensation pans underneath cooling coils should be designed and pitched to be self-draining. Yet, we have found countless condensation pans with standing water and microbial contamination because maintenance crews have never had the training or experience to see that pans drain properly. We often find thin fiberglass or metal screen prefilters used as the only particulate removal mechanism, because they are inexpensive. What is not considered is that prefilters are less than 20% efficient at dust removal. Morey and Shattuck recommend paper pleated air filters or bag filters with at least

60% dust removal efficiency. However, anytime a significant change is made in filter efficiency, airflow will be affected. Adjustments may be necessary to ensure adequate airflow.

As another example, inadequate balancing of ventilation systems often leads to marked variations in temperature over short distances in a building. The temperature may vary so widely in the same location over short periods of time that the anticipation of the next cold blast after a hot period detracts from attention to work. Balancing problems of this nature occur because the control equipment responsible for directing airflow is positioned in places inaccessible for maintenance. After a time the controls become unresponsive to central control. Other obvious reasons for HVAC failures are reduction of the HVAC maintenance work force to save personnel costs and the creation of new rooms with floor-to-ceiling partitions that disrupt proper airflow patterns.

The IAQ impact of other common HVAC decisions is subtler. For example, in many USAF buildings the HVAC system is turned off during unoccupied periods (evenings and weekends). With proper design and system scheduling, night setback/shutdown can be used. Ensure that a proper space ventilation purge cycle is used to reduce indoor air pollutants, and preheat/precool and humidity control is initiated prior to occupancy. Another common design decision is to not provide operable windows in buildings. Although they are not commonly found in most modern office buildings, windows that can be opened by the occupants have been effectively integrated with pressurized buildings and such designs can prevent a significant percentage of building IAQ problems, especially temporary temperature control of air contaminant problems (Loftness and Hartkopf, 1989).

HVAC System Components and Operation

The following information is from the EPA document, *Building Air Quality: A Guide for Building Owners and Facility Managers (1991).* All occupied buildings require a supply of outdoor air. Depending on outdoor conditions, the air may need to be heated or cooled before it is distributed into occupied space. As outdoor air is drawn into the building, indoor air is exhausted or allowed to escape (passive relief), thus removing air contaminants.

The term " HVAC system" is used to refer to the equipment that can provide heating, cooling, filtered outdoor air, and humidity control to maintain comfort conditions in a building. Not all HVAC systems are designed to accomplish all these functions. Some buildings rely only on natural ventilation. Others lack mechanical cooling equipment (AC), and many function with little or no humidity control. The features of the HVAC system in a given building will depend on several variables, including: age of design; climate; building codes in effect at the time of design; budget that was available for the project; planned use of the building; owners' and designers' individual preferences; and subsequent modifications.

HVAC systems range in complexity from stand-alone units that serve individual rooms to large centrally controlled systems serving multiple zones in a building. In large modern office buildings with heat gains from lighting, people, and equipment, interior spaces often require year-round cooling. Rooms at the perimeters of the same building (i.e., rooms with exterior walls, floors, or roof surfaces) may need to be heated and/or cooled as hourly or daily outdoor weather conditions change. In buildings over one story in height, perimeter areas at the lower levels also tend to experience the greatest uncontrolled air infiltration.

Some buildings use only natural ventilation or exhaust fans to remove odors and contaminants. In these buildings, thermal discomfort and unacceptable indoor air quality are particularly likely when occupants keep the windows closed because of extreme hot or cold temperatures. Problems related to under ventilation are also likely when infiltration forces are weakest (i.e., during the "swing seasons" and summer months).

Modern public and commercial buildings generally use mechanical ventilation systems to introduce outdoor air during the occupied mode. Thermal comfort is commonly maintained by mechanically distributing conditioned (heated or cooled) air throughout the building. In some designs, air systems are supplemented by piping systems that carry steam or water to building perimeter zones. As this (section of the) document is concerned with HVAC systems in relation to indoor air quality, the remainder of this discussion will focus on systems that distribute conditioned air to maintain occupant comfort.

Roles of the HVAC System Operator and Facility Manager

HVAC systems require preventive maintenance if they are to operate correctly and provide comfortable conditions for building occupants. In a properly designed, constructed, and commissioned HVAC system, the system operator and facility manager are among the most significant factors in determining whether IAQ problems will occur. The operator(s) must have an adequate understanding of the overall system design and its limitations. The HVAC system capacity and distribution characteristics should be evaluated before renovations to the building, changes in its occupancy, or changes in the use of an area.

System operators must be able to respond appropriately to occupant complaints. For example, if an occupant complains that it is too cold or too hot and the observed (measured) conditions are outside of the ASHRAE comfort zone, then the HVAC system needs to be evaluated. Sometimes the problem can be relieved by fine tuning or repairing the HVAC system, but in some cases the system cannot perform as expected, and a long-term solution must be investigated.

Types of HVAC Systems

Single Zone

- A single air-handling unit can only serve more than one building area if the areas served have similar heating, cooling, and ventilation requirements, or if the control system compensates for differences in heating, cooling, and ventilation needs among the spaces served. Areas regulated by a common control (e.g., a single thermostat) are referred to as zones. Thermal comfort problems can result if the design does not adequately account for differences in heating and cooling loads between rooms that are in the same zone. This can easily occur if:

- The cooling load in some area(s) within a zone changes due to an increased occupant population, increased lighting, or the introduction of new heat-producing equipment (e.g., computers, copiers).

- Areas within a zone have different solar exposures. This can produce radiant heat gains and losses that, in turn, create unevenly distributed heating or cooling needs (e.g., as the sun angle changes daily and seasonally).

Multiple Zone

- Multiple zone systems can provide each zone with air at a different temperature by heating or cooling the airstream in each zone. Alternative design strategies involve delivering air at a constant temperature while varying the volume of airflow, or modulating room temperature with a supplementary system (e.g., perimeter hot water piping).

Constant Volume

- Constant volume systems, as their name suggests, generally deliver a constant airflow to each space. Changes in space temperatures are made by heating or cooling the air or switching the air-handling unit on and off, not by modulating the volume of air supplied. These systems often operate with a fixed minimum percentage of outdoor air or with an "air economizer" feature.

Variable Air Volume

- Variable air volume systems maintain thermal comfort by varying the amount of heated or cooled air delivered, rather than by changing the air temperature. (However, many VAV systems also have provisions for resetting the temperature of the delivery air on a seasonal basis, depending on the severity of the weather). Overcooling or overheating can occur within a given zone if the system is not adjusted to respond to the load. Under ventilation frequently occurs if the system is not arranged to introduce at least the minimum quantity of outdoor air as the VAV system throttles back from full airflow, or if the system supply air temperature is set too low for the loads present in the zone.

Basic Components of an HVAC System

The basic components of an HVAC system that delivers conditioned air to maintain thermal comfort and indoor air quality may include:

- Outdoor air intake
- Mixed-air plenum and outdoor air control
- Air Filter
- Heating and cooling coils
- Humidification and/or de-humidification equipment
- Supply fan
- Ducts
- Terminal device (diffusers, VAV boxes etc.)
- Return air system
- Exhaust or relief fans and air outlet
- Self-contained heating or cooling unit
- Control
- Boiler
- Cooling Tower
- Water chiller
- Air-cooled condensing unit
- Heat pump

HVAC Duct Cleaning

The Industrial Hygiene Branch of AFIERA receives calls on a regular basis concerning duct cleaning. Most callers typically have a situation where there is visible dust, dirt or fungi on some or all supply air diffusers (grills) in a particular building. In most of these cases the assumption was made that the HVAC ducts need to be cleaned without doing a thorough inspection of the HVAC system. After further inspection, most callers find that the HVAC system is actually pretty clean and that the dust or dirt on the supply air diffusers is not coming from the HVAC system. Dust, dirt or even mold can occur on the air diffusers for several reasons without any problem or contamination of the HVAC system. Air flowing past the diffuser can create an electrical charge attracting dust particles. Cool air exiting the diffuser can cause moisture to condense on the vents allowing dirt to adhere providing a media for microbial growth. However, every case is unique, and a proper evaluation must be made to determine the extent of any contamination in the HVAC system.

This section will discuss the evaluation of an HVAC system, how to decide if HVAC duct cleaning is needed, and available guidelines for the cleaning of ducts. The EPA has published a guide titled, <u>Should You Have the Air Ducts in Your Home Cleaned</u> (1997), aimed at residential occupants, but the same principles apply to office buildings with HVAC systems. In addition, in the EPA publication, <u>Building Air Quality</u> (1991), duct cleaning is discussed. The following information has been extracted from these two EPA publications.

The same HVAC system that distributes conditioned air throughout a building can distribute dust and other pollutants, including biological contaminants. Dirt or dust accumulation on any components of an air handling system – its cooling coils, plenums, ducts, and equipment housing – may lead to contamination of the air supply.

<u>You should consider having the air ducts cleaned if:</u>

1. There is substantial visible mold growth inside hard surface (e.g., sheet metal) ducts or on other components of your heating and cooling system. There are several important points to understand concerning mold detection in heating and cooling systems:

    - Many sections of your heating and cooling system may not be accessible for a visible inspection, so ask the service provider to show you any mold they say exists.

    - You should be aware that although a substance may look like mold, a positive determination of whether it is mold or not, can be made only by an expert and may require laboratory analysis for final confirmation. We can recommend a laboratory that can tell you whether a sample sent to them is mold or simply a substance that resembles it.

    - If you have insulated air ducts and the insulation gets wet or moldy it cannot be effectively cleaned and should be removed and replaced.

- If the conditions causing the mold growth in the first place are not corrected, mold growth will recur.

2. Ducts are infested with vermin, (e.g. rodents or insects)

3. Ducts are clogged with excessive amounts of dust and debris and/or particles are being released into the building from the supply registers.

Other Important Considerations

Duct cleaning has never been shown to actually prevent health problems. Studies have not conclusively demonstrated that particle (e.g., dust) levels in homes increase because of dirty air ducts or go down after cleaning. This is because much of the dirt that may accumulate inside air ducts adheres to duct surfaces and does not necessarily enter the living space. It is important to keep in mind that dirty air ducts are only one of many possible sources of particles that are present in buildings. Pollutants that enter a building both from outdoors and indoor activities such as cooking, cleaning, smoking, or just moving around can cause greater exposure to contaminants than dirty air ducts. Moreover, there is no evidence that a light amount of household dust or other particulate matter in air ducts poses any risk to health.

The EPA does not recommend that air ducts be cleaned except on an as-needed basis because of the continuing uncertainty about the benefits of duct cleaning under most circumstances. If a service provider or advertiser asserts that the EPA recommends routine duct cleaning or makes claims about its health benefits, you should notify the EPA. The EPA does, however, recommend that if you have a fuel burning furnace, stove, or fireplace, they be inspected for proper functioning and serviced before each heating season to protect against carbon monoxide poisoning. Some research also suggests that cleaning dirty cooling coils, fans and heat exchangers can improve the efficiency of heating and cooling systems. However, little evidence exists to indicate that simply cleaning the duct system will increase your system's efficiency.

(NOTE: Bioenvironmental engineering personnel will need to discuss duct cleaning with Civil Engineering personnel. Work with CE HVAC technicians and engineers when deciding whether dust cleaning is needed and when choosing a duct cleaning service. Contracts for duct cleaning must be coordinated through CE.)

EPA Guidelines for Duct Cleaning

Listed below, as a general overview, are the EPA's recommendations concerning duct cleaning.

1. Any duct cleaning should be scheduled during periods when the building is unoccupied to prevent exposure to chemicals and loosened particles.

    - The air-handling unit should not be used during the cleaning or as an air movement device for the cleaning process. The National Air Duct Cleaning Association recommends that the system should be run to allow at least eight air changes in the occupied space when duct cleaning has been completed.

2. Negative air pressure that will draw pollutants to a vacuum collection system should be maintained at all times in the duct cleaning area to prevent migration of dust, dirt, and contaminants into occupied areas.

    - Where possible, use vacuum equipment or fans during cleaning and sanitizing to make sure that cleaning vapors are exhausted to the outside and do not enter the occupied space.

3. If it is determined that the ductwork should be cleaned, careful attention must be given to protecting the ductwork.

    - When gaining access to sheet metal ducts for cleaning purposes, it is essential to seal the access hole properly in order to maintain the integrity of the HVAC system. Access doors are recommended if the system is to be cleaned periodically, and all access holes should be identified on the building's mechanical plans.

    - Particular attention is warranted when cutting fibrous glass ducts, and manufacturers' recommended procedures for sealing should be followed stringently. Use existing duct system openings where possible because it is difficult to repair the damage caused by cutting new access entries into the ductwork. Large, high volume vacuum equipment should only be used with extreme care because high negative pressure together with limited airflow can collapse ducts.

    - Duct cleaning performed with high velocity airflow (i.e., greater than 6,000 cfm) should include gentle, well-controlled brushing of duct surfaces or other methods to dislodge dust and other particles.

    - Duct cleaning that relies only on high velocity airflow through the ducts is not likely to achieve satisfactory results because the flow rate at the duct surface remains too low to remove many particles.

4. Only HEPA filtered (high-efficiency particle arrestor) vacuuming equipment should be used if the vacuum collection unit is inside the occupied space.

    - Conventional vacuuming equipment may discharge extremely fine particulate matter back into the atmosphere, rather than collecting it. Duct cleaning equipment that draws the dust and dirt into a collection unit outside the building is also available. People should not be allowed to remain in the immediate vicinity of these collection units.

5. If biocides are to be used, then select only products registered by EPA for such use, use the products according to the manufacturer's directions, and pay careful attention to the method of application.

    - At present, EPA accepts claims and therefore registers antimicrobials for use only as sanitizers, not disinfectants or sterilizers in HVAC systems. There is some question about whether there are any application techniques that will deposit a sufficient amount of the biocide to kill bacteria, germs, or other biologicals that may be present. Materials such as deodorizers that temporarily eliminate odors caused by microorganisms provide only a fresh smell, and are not intended to provide real control of microbiological contaminants.

6. Use of sealants to cover interior ductwork surfaces is not recommended.

    - No application techniques have been demonstrated to provide a complete or long-term barrier to microbiological growth, nor have such materials been evaluated for their potential health effects on occupants. In addition, using sealants alters the surface burning characteristics of the duct material and may void the fire safety rating of the ductwork.

7. Careful cleaning and sanitizing of any parts of coils and drip pans can reduce microbiological pollutants.

    - Prior to using sanitizers, deodorizers, or any cleansing agents, carefully read the directions on the product label. Once cleaned, these components should be thoroughly rinsed and dried to prevent exposure of building occupants to the cleaning chemicals.

8. Water-damaged or contaminated porous materials in the ductwork or other air handling system components should be removed and replaced. If there is a source of condensate in the ductwork it should be identified and eliminated, otherwise the problem will reoccur.

    - Even when such materials are thoroughly dried, there is no way to guarantee that all microbial growth has been eliminated.

9. After the duct system has been cleaned and restored to use, a preventive maintenance program will prevent the recurrence of problems.

    - Such a program should include particular attention to the use and maintenance of adequate filters, control of moisture in the HVAC system, and periodic inspection and cleaning of HVAC system components.

Energy Efficiency

Building managers and engineers are often resistant to increasing fresh air because this appears to defeat energy conservation efforts. Our response is two-fold: first, HVAC Systems can be made energy efficient without compromising the fresh air quantity; and second, the cost of human productivity losses far outweigh any savings realized by minimizing fresh air.

The EPA (2000) states that increasing outdoor air to meet ASHRAE Standard 62-1999 in most of the office buildings in their study resulted in very modest increases in energy costs. The table below describes methods to reduce energy use while maintaining IAQ. The main factor affecting the energy cost of raising outdoor airflow was occupant density, such that buildings with higher occupant density experienced higher energy cost increases. But for office buildings with 7 persons per thousand square feet, with moderate chiller and boiler efficiencies, and operating in daytime mode for 12 hours per workday, raising outdoor airflow from 5-20 cfm (2 - 9 L/s) per occupant raised HVAC energy costs by 2% - 10% depending upon system and climate variations. Considering the total energy bill, this increase amounted to approximately 1% - 4%. This is generally less than is commonly perceived and suggests that the issue needs a more careful examination by practitioners.

With increased use of outdoor air, cooling cost increases in the summer months were counterbalanced by cooling cost savings during cooler weather. Cost increases were higher for economizer systems than systems without economizers because the economizer already captured much of the cost savings from higher outdoor airflow rates during cooler weather. For buildings with occupant densities of 3 persons per thousand square feet, energy cost increases were less. By contrast, office buildings modeled with 15 persons per 1000 square feet experienced up to 21% increase in HVAC energy (or up to 8% increase in the total energy bill).

Table 3. Energy Measures Compatible with Maintaining IAQ (EPA 2000)

Measure	Comment
Improve building shell	- May reduce infiltration. May need to increase mechanically supplied outdoor air to ensure applicable ventilation standards are met.
Reduce Internal loads (e.g. lights, office equipment)	- Reduced loads will reduce supply air requirements in VAV systems. May need to increase outdoor air to meet ventilation standards. - Lighting must be sufficient for general and task lighting needs.
Fan/motor/drives	- Negligible impact on IAQ.
Chiller/boiler	- Negligible impact on IAQ.
Energy recovery	- May reduce energy burden of outdoor air, especially in extreme climates and/or when high outdoor air volumes are required.
Air-side economizer	- Uses outdoor air to provide free cooling. Potentially improves IAQ when economizer is operating by helping to ensure that the outdoor air ventilation rate meets IAQ requirements. - On/off set points should be calibrated to both the temperature and moisture conditions of outdoor air to avoid indoor humidity problems. May need to disengage economizer during an outdoor air pollution episode.
Night pre-cooling	- Cool outdoor air at night may be used to pre-cool the building while simultaneously exhausting accumulated pollutants. However, to prevent microbiological growth, controls should either halt pre-cooling or activate dehumidification if the dew point of outside air is high enough to cause humidity to rise above 60%.
Preventive maintenance (PM) of HVAC	- PM will improve IAQ and reduce energy use by removing contaminant sources (e.g. clean coils/drain pans), and insuring proper calibration and efficient operation of mechanical components (e.g. fans, motors, thermostats and controls).
CO_2 controlled ventilation	- CO_2 controlled ventilation varies the outdoor air supply in response to CO_2, which is used as an indicator of occupancy. May reduce energy use for general meeting rooms, studios, theaters, educational facilities etc. where occupancy is highly variable, and irregular. A typical system will increase outdoor air when CO_2 levels rise to 600-800 ppm to ensure that maximum levels do not exceed 1000 ppm. The system should incorporate a minimum outside air setting to dilute building related contaminants during low occupancy periods.
Reducing demand charges	- Night pre-cooling and sequential startup of equipment to eliminate demand spikes are examples of strategies that are compatible with IAQ. Caution is advised if load-shedding strategies involve changing the space temperature set points or reducing outdoor air ventilation.
Supply air temperature reset	- Supply air temperature may sometimes be increased to reduce chiller energy use. However, fan energy will increase. Higher supply air temperatures in a VAV system will increase supply airflow. Note that the supply air temperature should not be raised above a level where indoor humidity cannot be maintained below 60%

Productivity and Economic Impact

Lyles et al. (1991) summarize the overall effect of poor IAQ with the statement that "Sick Building Syndrome is one of the most common and increasingly frequent afflictions of the office worker, leading to significant morbidity, decreased productivity, job dissatisfaction, and stress." Burge et al. (1987), in their study of over 4,000 office workers, conclude that IAQ problems are widespread throughout modern countries.

The World Health Organization has estimated that 30% of new or renovated office buildings have identifiable IAQ problems (Lyles et al., 1991). The general nature of this phenomenon translates into a huge productivity loss. Mudarri (1991) reports a New England study of 3,500 office workers in which 54% felt poor IAQ resulted in some productivity loss for themselves. Using the most conservative interpretation of this data, Mudarri estimated an overall 3% loss in national productivity, which equates to $60 billion in lost time per year. According to the National Center for Health Statistics, the average number of respiratory infections involving colds and flu is one per person per year. Tight buildings can increase that number to between 1.5 and 3.0 episodes per person per year, which can double the cost of so-called energy efficient measures (Carpenter and Poitrast, 1990).

Wyon (1991) has reported some specific productivity losses. Typing productivity dropped by 30% at a room temperature of 23.8^{o}C compared to 20^{0}C (68^{0}F). His data also show assembly line production drops by 1% for each 1.1^{o}K (2^{o}F) variation from the ideal, and truck drivers miss 50% more signals at 26.6^{o}C (81^{o}F) compared to 21.1^{o}C (70^{o}F). Workers who had individualized control over their temperature had 69% fewer sick days than those under centralized temperature control. Wyon also found that persons not currently suffering from IAQ symptoms are 5% more productive than when they suffer two symptoms (an average figure in offices). In addition, persons suffering from 6 or more symptoms (not unusual) are 10% less productive than when they suffer from two symptoms.

This productivity loss can be directly compared to the costs of energy, operation, and maintenance for HVAC systems. Woods (1989) has figured that in an average building with "100 ft^2/person," the salary costs of employees are $237/$ft^2$"; construction of the facility and equipping it for office work costs "$63/$ft^2$" amortized over the life of the building; operation and maintenance costs are "$10/$ft^2$"; and energy costs for the HVAC are "$2/$ft^2$." A simple evaluation of the costs shows that a 5% savings in energy costs gained by reducing the amount of outside air is counterproductive if just 0.1% in productivity is lost (or 24 seconds per person per day). A 25% savings in operation and maintenance by reducing manning is counterproductive if 2.5% in productivity is lost (or 10 minutes per person per day). Mudarri (1991) and Offermann and Gilbertson (1991) have come up with very similar cost estimates for the general workforce.

In several buildings, we have calculated productivity loss figures based on sick leave. The average sickness absence rate reported by the Bureau of Labor Statistics is 3.6 days per person per year. Our data from "healthy" buildings in the USAF agrees with this figure. In a typical building with IAQ problems, we have found the sickness absence rate to be approximately 9 days per person per year. (Sickness absence rates are determined by collecting sick leave data from civilian timekeepers and subtracting out sick leave obviously unrelated to the building, such as pregnancy, injury, or alcohol abuse.) Based on sickness absence alone and 220 work days per year, the productivity loss in an average building with poor IAQ is (9 - 3.6)/220, or 2.5%. Add this time lost on the job suffering from IAQ symptoms, such as the 5% figure from Wyon (1991), and it becomes obvious that operating an HVAC system properly with the proper level of maintenance is more cost-effective than any attempt to save money by cutting down the fresh air or reducing the maintenance staff.

REFERENCES

1. Aerotech Laboratories. IAQ Microbiology Reference Guide, 2002.

2. American Conference of Governmental Industrial Hygienists. Bioaerosols: Assessment and Control. Cincinnati, OH: ACGIH, 1999.

3. American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. Cincinnati, OH: ACGIH, 1991.

4. American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. Cincinnati, OH: ACGIH, 2001.

5. Air Force Handbook 32-1084. Facility Requirements, Chapter 12, Administrative Facilities, 1996.

6. Air Force Instruction 32-1024. Standard Facility Requirements, 1994.

7. Air Force Instruction 40-102. Tobacco Use in The Air Force, 2002.

8. Air Force Instruction 48-145. Occupational Health Program, 1999.

9. American College of Occupational and Environmental Medicine (ACOEM). Adverse Human Health Effects Associated with Molds in the Indoor Environment, 2002.

10. American Standard Inc, A Guide to Understanding ASHRAE Standard 62-2001, 2002.

11. Anderson, R. Measuring Respiratory Irritancy of Emissions. Healthy Buildings—IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C. Sept 5-8, 1991.

12. ASHRAE Standard 55-1992. Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA, 1992.

13. ASHRAE Standard 62-1989. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA, 1989.

14. ASHRAE Standard 62-1999. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA, 1999.

15. ASHRAE Standard 62-2001. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA, 2001

16. Berglund, B., Lindvall, T. (ed.). Conclusions and Recommendations for Healthier Buildings. Healthy Buildings 1988; Vol. 4: Swedish Council for Building Research. Stockholm, Sweden, 1991.

17. Besch, E.L. Regulation and Its Role in the Prevention of Building-Associated Illness. Occupational Medicine: State of the Art Reviews. 4: 741-752, Oct-Dec 1989.

18. Besch, E.L., Besch, H.J. Managing an Indoor Air Quality (IAQ) Problem in a Public Building. Proceedings of the ASHRAE/SOEH Conference, IAQ '89, The Human Equation: Health and Comfort, 1989.

19. Bright, P.D., Mader, M.J., Carpenter, D.R., Hermon-Cruz, I.Z. Guide For Indoor Air Quality Surveys. AL-TR-1992-0016, 1992.

20. Brundage, J.F., Scott, R., Lednar, W., et al. Building Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees. JAMA; 259: 2108-2112, 1988.

21. Burge, H.A. Indoor Air and Infectious Disease. Occupational Medicine: State of the Art Reviews. 4: 713-721, Oct-Dec, 1989.

22. Burge, H.A., Hoyer, M.E. Focus on Indoor Air Quality. Applied Occupational and Environmental Hygiene. 5: 84-93, Feb 1990.

23. Burge, S., Hedge, A., Wilson, S., Bass, J.H., Robertson, A. Sick Building Syndrome: A Study of 4373 Office Workers. Annals of Occupational Hygiene. 31: 493-504, 1987.

24. Burton, D.J. Engineering Control, A Series of Columns on Indoor Air Quality. Occupational Health and Safety. June 1990-July 1991.

25. Carpenter, D.R., Poitrast, B.J. Recommended Carbon Dioxide and Relative Humidity Levels for Maintaining Acceptable Indoor Air Quality. AFOEHL Report 90-169, 1990.

26. DHHS-NIOSH. Indoor Air Quality, Selected References, 1989.

27. Environmental Protection Agency. Building Air Quality: A Guide for Building Owners and Facility Managers, 1991.

28. Environmental Protection Agency. Flood Cleanup: Avoiding Indoor Air Problems (402-F-93-005), 1993.

29. Environmental Protection Agency. "Should You Have the Air Ducts in Your Home Cleaned?" EPA-402-K-97-002, October 1997.

30. Environmental Protection Agency. Energy Cost and IAQ Performance of Ventilation Systems and Controls. January 2000.

31. Fanger, P.O. Ventilation to Handle Pollution from Building and Occupants. Healthy Buildings—IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

32. Federal Register (56) 47892. OSHA Request for Information on Occupational Exposure to Indoor Air Pollutants, 1991.

33. Federal Register (59) 15968-16039. OSHA Proposed Rulemaking for an Indoor Air Quality Standard, 1994.

34. Johnson, B.C., Kronvall, J., Lindvall, T., Pettersson, B., Wallin, A., Weiss Lindencrona, H. Buildings and Health: Indoor Climate and Effective Energy Use, Summary. Swedish Council for Building Research, Stockholm, Sweden, 1991.

35. Jones, W. Horizons: Sick Building Syndrome. Applied Occupational and Environmental Hygiene. 5: 74-83, February 1990.

36. Kreiss, K. The Epidemiology of Building Related Complaints and Illness. Occ. Med. State Art Rev. 4: 575-592, 1989.

37. Liebhaber, Frank. A Procedural Guide on Sick Building Syndrome. AFOEHL Report 87-037, 1987.

38. Loftness, V., Hartkopf, V. The Effects of Building Design and Use on Air Quality. Occupational Medicine: State of the Art Reviews. 4: 643-665, Oct-Dec 1989.

39. Lyles, W.B., Greve, K.W., Bauer, R.M., Ware, M.R., Schramke, C.J., Crouch, J., Hicks, A. Sick Building Syndrome. Southern Medical Journal. 84: 64-72, Jan 1991.

40. Millar, J.D. Health Hazards of Airborne Fungi. PathCon Protocol 2:21-22. 1996.

41. Moffatt, P., Moffatt, S., Cooper, K. Final Report: Demand Controlled Ventilation. A Research Report Submitted to Research Division, Canada Mortgage and Housing Corporation, 1991.

42. Molhave, L., Bach, B., Pedersen, O.F. Human Reactions to Low Concentrations of Volatile Organic Compounds. Environment International. 12: 167-175, 1986.

43. Morey, P.R., Shattuck, D.E. Role of Ventilation in Building Associated Illness. Occ. Med. State Art Rev. 4: 625-642, 1989.

44. Morey, P.R., Woods, J.E. Indoor Air Quality in Health Care Facilities. Occ. Med. State Art Rev. 2: 547-563, 1987.

45. Morris, G.K. and B.G. Shelton. A Suggested Air Sampling Strategy for Microorganisms in Office Settings. PathCon Technical Bulletin 2.5. 1998.

46. Morris, G.K. and B.G. Shelton. Legionella Bacteria in Environmental Samples: Hazard Analysis and Suggested Remedial Actions. PathCon Technical Bulletin 1.5. 1998.

47. Mosher, C. et al. Unusually Aggressive Transmission Tuberculosis in a Factory. J. Oct. Med. 29: 29-31, 1987.

48. Mudarri, D. Quantifying Costs and Benefits of Healthy Buildings. Healthy Buildings—IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

49. New York City Department of Health Bureau of Environmental & Occupational Disease Epidemiology. Guidelines on Assessment and Remediation of Fungi in Indoor Environments. April 2000.

50. Neville, J. Mold Sampling Procedures, 2003.

51. NIOSH. Current Intelligence Bulletin No. 54, Environmental Tobacco Smoke in the Workplace. Occupational Safety & Health Reporter; 7-24-91; pp. 232-234. 1991.

52. NIOSH. Indoor air quality, selected references. Cincinnati: National Institute of Occupational Safety and Health. 1989.

53. NKB Publication No. 61E. Indoor Climate - Air Quality. Nordic Committee on Building Regulations. June 1991.

54. Offermann, F.J. III, Gilbertson, T.A. How to Meet New Ventilation Standards: Indoor Air Quality and Energy Efficiency. Association of Energy Engineers (AEE) Seminar. Atlantic City, N.J. Nov 18-19, 1991.

55. Pathogen Control Associates, Inc. CDC Repudiates Its Prior Report of a Link Between Pulmonary Hemorrhage in Infants and Stachybotrys: Results of a Two-year Review. PathCon Protocol 4:29-33, 2000.

56. Pritchard, J.A. A Guide to Industrial Respiratory Protection. NIOSH Pub. No. 76-189. Cincinnati, 1976.

57. Quinlan, P., Macher, J.M., Alevantis, L.E., Cone, J.E. Protocol for the Comprehensive Evaluation of Building-Associated Illness. Occupational Medicine: State of the Art Reviews. 4: 771-797, Oct-Dec 1989.

58. Rajhans, G.S. Findings of the Ontario Inter-Ministerial Committee On Indoor Air Quality. Proceedings of the ASHRAE/SOEH Conference, IAQ '89, The Human Equation: Health and Comfort, 195-223, 1989.

59. Rajhans, G.S. Indoor Air Quality and CO_2 Levels. Occupational Health in Ontario. 4: 160-167, 1983.

60. Red Cross and Federal Emergency Management Agency. Repairing Your Flooded Home, 1992.

61. Shelton, B.G., Morris, G.K. Bacteria and Fungi in Indoor Environments: Pathogens and Other Microorganisrns Requiring Immediate Remedial Action. 1991 American Industrial Hygiene Conference and Exposition, Salt Lake City, UT; Paper # 69.

62. Shelton, B.G., et al. Mycobacterium spp. as a Possible Cause of Hypersensitivity Pneumonitis in Machine Workers. Emerging Infectious Diseases 5:270-273. 1999

63. Stolwijk, Jan A. J. Shelter and Indoor Air. Environmental Health Perspective. 86: 271-274, 1990.

64. Strindehag, O., Norell, L., Kvarnstrom, S. Improved Indoor Air Quality by Supervision of the CO_2 Content. Indoor Air '90, The Fifth International Conference on Indoor Air Quality, Toronto; 4: 437-442, 1990.

65. Sundell, J. Comments during Workshop on Performance Guidelines for Controlling IAQ by Ventilation. Healthy Buildings—IAQ '91, Planning, Designing, Constructing, Renovating, and Occupying Buildings: Recommendations and Benefits, Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

66. Teichman, K. ASHRAE 62-1989. An Environmental Health Perspective. Healthy Buildings—IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: Recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

67. Wallingford, K.M. NIOSH Indoor Air Quality Investigations in Non-industrial Workplaces, Update '86. American Industrial Hygiene Conference, paper #18. 1986.

68. Woods, J.E. Cost Avoidance and Productivity in Owning and Operating Buildings. Occupational Medicine: State of the Art Reviews. 4: 753-770, Oct-Dec, 1989.

69. Wyon, D. Overcoming Barriers to Productivity in Healthy Buildings. Healthy Buildings—IAQ '91, Planning, Designing, Constructing, Renovating and Occupying Buildings: recommendations and Benefits. Organized by ASHRAE and the International Council for Building Research, Studies and Documentation (CIB). Washington, D.C., Sept 5-8, 1991.

APPENDIX A

QUESTIONNAIRE

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INDOOR ENVIRONMENTAL QUALITY SURVEY BUILDING ________

This questionnaire is being distributed to assess the satisfaction of building occupants with building conditions. Your cooperation in giving us accurate data is appreciated. Answer the questions below as accurately as possible.

NAME (Optional)	ROOM	WORK PHONE

I. WORKPLACE INFORMATION

1. During what period of time did you work in this building? In which room?

From:______________ To:_______________ Room:______________

From:______________ To:_______________ Room:______________

From:______________ To:_______________ Room:______________

From:______________ To:_______________ Room:______________

From:______________ To:_______________ Room:______________

2. On average, how many HOURS per WEEK do you work in this building?
___ Hours per week

3. During the LAST WEEK, how many days did you work in this building?
___ Days

4a. Which best describes the space in which your current workstation is located?

__ Private office
__ Shared private office
__ Open space with partitions
__ Open space without partitions
__ Other (specify)
____

4b. How many people work in the room in which your workstation is located (including yourself)?
__ 1 __ 2-3 __ 4-7 __ 8 or more

5. Is there carpeting on most or all of the floor at your workstation?
__ Yes __ No

6. In general, how clean is your workspace area?

__ Very clean
__ Reasonably clean
__ Somewhat dusty or dirty
__ Very dusty or dirty

7. Please rate the lighting at your workstation.

__ Much too dim
__ A little too dim
__ Just right
__ A little too bright
__ Much too bright

8. Do you experience a reflection or "glare" in your field of vision when at your workstation?

__ Rarely
__ Occasionally
__ Sometimes
__ Fairly often
__ Very often

9. How comfortable is the current set-up of your desk or worktable? (i.e., height and general arrangement of the table, chair, and equipment you work with)

__ Very comfortable
__ Reasonably comfortable
__ Somewhat uncomfortable
__ Very uncomfortable
__ Don't have one specific desk or work table

10a. About how many HOURS per DAY do you work with a computer or word processor, to the nearest hour?

__ Hours per day   __ Don't use one

10b. If you use a computer or word processor, do you usually wear glasses when you use these machines?

__ Yes   __ No   __ Not Applicable

10c. Do you use a glare screen on your computer?

__ Yes   __ No   __ Not Applicable

11. Which one of the following statements best describes the windows in your work area?

__ There are no windows in my personal workspace and none in the general area visible from my workspace (when I am either standing or seated).

__ There are no windows in my personal workspace, but I can see one or more windows in the general area.

__ There are one or more windows in my personal workspace.

12. If there is a window visible from your workspace, about how far (in feet) is the closest window from your desk chair?

____ feet   ___ Check here if no window

13. During the PAST THREE MONTHS, have the following changes taken place within 15 feet of your current workstation?

	YES	NO
New carpeting	__	__
Walls painted	__	__
New furniture	__	__
New partitions	__	__
New wall covering	__	__
Water damage	__	__

14. How often do you use the following at work? (Check the appropriate box for each item.)

	Several times a day	About once a day	3-4 times a week	Less than 3 times/week	Never
Photocopier	__	__	__	__	__
Laser printer	__	__	__	__	__
Facsimile (FAX) machine	__	__	__	__	__
Self-copying (carbonless) copy paper	__	__	__	__	__
Cleanser, glue, correction fluid, or other strong-smelling chemical	__	__	__	__	__

15. Do you presently have any of the following pets at your home?

Dog: __ Yes __ No Cat: __ Yes __ No
Bird: __ Yes __ No
Other: ____________________________

II. INFORMATION ABOUT HEALTH AND WELL-BEING

1. Have you ever been told by a doctor that you have or had any of the following?

	YES	NO	**If yes for sinus infection or asthma, in approximately what year was the diagnosis first made?**
Sinus infection	__	__	_______
Asthma	__	__	_______
Migraine	__	__	
Eczema	__	__	
Hay fever	__	__	
Allergy to dust	__	__	
Allergy to molds	__	__	
Allergy to cats	__	__	
Other:__________________			

2. What is your alcohol consumption status?

__ None
__ 1 to 4 drinks weekly
__ 1 to 2 drinks daily
__ More than two drinks daily

3. What is your tobacco smoking status?

__ Never smoked

__ Former smoker
How many cigarettes per day ______
Number of months/years smoked_________
When did you quit_________

__ Current smoker
How many cigarettes per day ______
Number of months/years smoked_________

4. Do you consider yourself especially sensitive to the presence of tobacco smoke?

__ Yes(1) __ No

5. Do you consider yourself especially sensitive to the presence of chemicals in the air of your workspace?

__ Yes(1) __ No

6. Do you follow a balanced nutritional diet?

__ Yes(1) __ No

7. Do you exercise at least 20 minutes three times a week?

__ Yes(1) __ No

8. What type of corrective lenses do you usually wear at work? (Check all that apply)

__ None
__ Glasses
__ Bifocals
__ Contact lenses

9. How old were you on your last birthday?

__ under 20 __ 20-29 years __30-39 years
__ 40-49 years __ 50-59 years __ over 59 years

10. Are you:

__ Male __ Female

11. Are you currently seeing a doctor for treatment of a medical condition that is related to the building?

Yes ____ No ____ **If yes, please list the condition below.**

____

____

12.	How often have you experienced each of the following symptoms while working in this building?				What happened to symptoms in last month while away from work?			At work today?	
SYMPTOMS	Not in last month	1-3 days in last month	1-3 Days per week in last month	Almost or every workday in last month	Got worse	Stayed the same	Got better	Yes	No
Dry/itching/irritated eyes									
Wheezing									
Headache									
Ringing in ears									
Sore or dry throat									
Unusual tiredness, fatigue, drowsiness									
Chest tightness									
Cough									
Stuffy/runny nose, sinus congestion,									
Toothache									
Tired or strained eyes									
Tension/irritability/ nervousness									
Leg cramps									
Pain/ stiffness back/shoulders/neck									
Memory/ concentration problems									
Dizziness/ lightheaded									
Feeling depressed									
Shortness of breath									
Hiccups									
Nausea or upset stomach									
Dry or itchy skin									

13. Is there a family history of diseases? (heart disease, hypertension, asthma, lung disease, kidney disease, diabetes, neurological disease, cancer, other)

Yes ____ No ____ **If yes, please describe relationship to family member below.**

____

____

____

III. DESCRIPTION OF WORKPLACE CONDITIONS

	How often have you experienced each of the following conditions while working in this building?				At work today?	
CONDITIONS	Not in last month	1-3 days in last month	1-3 Days per week in last month	Almost or every workday in last month	Yes	No
Too much air flow						
Too little air flow						
Too hot						
Too cold						
Too humid						
Too dry						
Tobacco odors						
Chemical odors						
Other unpleasant odors						

IV. CHARACTERISTICS OF YOUR JOB

1. What is your job category?

__ Managerial
__ Professional
__ Technical
__ Secretarial or Clerical
__ Other (specify)__________________

2. All in all, how satisfied are you with your job?

__ Very satisfied
__ Somewhat satisfied
__ Not too satisfied
__ Not at all satisfied

3. What is the highest grade you completed in school?

__ 8th grade or less
__ Some high school
__ High school graduate
__ Some college
__ College degree
__ Graduate degree

4. Conflicts can occur in any job. For example, someone may ask you to do work in a way that is different from what you think best, or you may find that it is difficult to satisfy everyone. HOW OFTEN do you face problems in your work like the ones listed below? (Check the appropriate blank for each statement).

	Rarely	Occasionally	Sometimes	Fairly often	Very often
Persons equal in rank and authority over you, ask you to do things which conflict.					
People, in a good position to see if you do what they ask, give you things which conflict with one another					
People, whose requests should be met, give you things which conflict with other work you have to do					

5. The next series of questions asks HOW OFTEN certain things happen AT YOUR JOB. (Check the appropriate blank for each question.)

	Rarely	Occasionally	Sometimes	Fairly often	Very often
How often does your job require you to work very fast?					
How often does your job require you to work very hard?					
How often does your job leave you with little time to get things done?					
How often is there a great deal to be done?					
How often are you clear on what your job responsibilities are?					
How often can you predict what others will expect of you on the job?					
How much of the time are your work objectives well defined?					
How often are you clear about what others expect of you on the job?					

6. The next series of questions asks about responsibilities OUTSIDE YOUR NORMAL WORKING DAY. Do you currently have the following responsibilities?

	Yes	No
Major responsibility for childcare duties		
Major responsibility for housekeeping duties		
Major responsibility for care of an elderly or disabled person on a regular basis		
Regular commitment of five hours or more per week, paid or unpaid, outside of this job (include educational courses, volunteer work, second job, etc.)		

7. Please describe your hobbies or other activities outside your normal workday (For example woodworking, stained glass design, car repairs, athletics, other jobs)

____

____

____

____

PLEASE USE THE REMAINING SPACE TO DISCUSS ANY ASPECTS OF THE BUILDING ENVIRONMENT OR EMPLOYEE HEALTH THAT YOU FEEL APPROPRIATE.

____

____

____

____

____

APPENDIX B

EQUIPMENT CHECKLIST

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Basic Equipment for Indoor Air Quality Survey

Carbon Dioxide, Temperature and Relative Humidity:
- Indoor Air Quality Monitors (Metrosonics AQ-501 or equivalent) <u>OR</u>
- CO_2 Monitors with strip chart recorders or data loggers
- Sling psychrometers or hygrothermographs

Velocity and Air Flow Measurements:
- Flow Hood (for supply and exhaust vent air flow)
- Rotating vane anemometer (for air velocity)

Contaminant Screening:
- Flame Ionization Detector (FID) or Photo ionization Detector (PID) (calibrated with hexane for organic detection)
- Color Detector Tubes for carbon monoxide, ammonia, sulfur dioxide, nitrogen dioxide, hydrogen sulfide, and ozone

Volatile Organics (Total VOCs & Formaldehyde):
- NOTE:Coordinate VOC sampling in advance with the AFIERA analytical lab
- Charcoal Tubes (l00 mg/50 mg, charcoal shell)
- Sampling Pumps (calibrated at 200 cc/min)
- 3M 3721 Passive Dosimeters for Formaldehyde

Biological Sampling:
- Sampler and Sampling Media. (Coordinate with AFIERA to obtain samplers, media, and supplies from contract lab)

Supplies:
- Flashlight (it's dark inside an air handler)
- Tape Measure
- Tool Kit (screwdrivers, hex nut wrenches)
- Extension Cords
- Labels for Samples

Notes:

- You may not need all the equipment on the list for each survey. Results from the questionnaires, walk-through and professional judgment will determine what equipment to use. Other equipment may be necessary for special surveys.

- The FID and PID are excellent tools for the detection of organic material leaks, but they are not absolutely necessary. A PID cannot detect methane.

APPENDIX C

IAQ TROUBLESHOOTING GUIDELINES

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Table 4. IAQ Troubleshooting Guidelines

Cause	Symptom/Complaint	Observation	Recommendation
Low relative humidity	• Dry, scratchy eyes, nose or throat • Sore throat • Can't wear contact lenses • Headache or bodyache • Sinusitis	• Relative humidity less than 40%	• Re-humidify air in air handlers
High CO_2 concentration	• Sleepiness • Fatigue • Poor concentration • Restlessness • Stuffy feeling • Sensation of breathing difficulty	• CO_2 levels elevated, especially in the afternoon • Fresh air dampers nearly closed • No supply air in room or supply air blocked.	• Increase fresh air rate • Open dampers • Decrease density of occupants • Add supply vents • Rearrange office
Improper HVAC balance	• Hot/cold spots • Stuffy feeling	• High CO_2 levels • Airflow imbalance	• Rebalance HVAC system
Negative pressure building	• Hot/cold spots • Dusty	• Wide temperature variations • Doors slam shut or are hard to open • Supply flow rate less than return • Humidity damaged paint, wallpaper	• Increase supply air fan to 5% greater than return fan • Rebalance HVAC system
Fiberglass insulation dust	• Irritative cough • Dermatitis	• Dust/fibers in room or air handler • Exposed insulation in air handling unit (AHU)	• Replace or remove insulation • Vacuum ducts • Clean AHU

Cause	Symptom/Complaint	Observation	Recommendation
Bioaerosols	• Allergy confined to building • Musty smell • Nausea/diarrhea	• Water stained ceiling • Drip pans with standing water • Mold smell • Visible mold growth • Humidity > 70%	• Clean and disinfect HVAC system • Replace filters • Eliminate water source
Pollution source	• Smells • Headaches • Nausea/Diarrhea	• Fresh air intake located near loading dock/road/water tower • Combustion source in return air • No J-traps on drains or traps are dry	• Relocate fresh air intake • Remove combustion source • Add J-traps and fill with water • Absorb offending chemical
Cigarette smoke	• Tobacco smell • Complaints about smokers	• CO more than 2 ppm • Tobacco smoke in return air	• Move smoking area • Ban smoking
Air handler neglect	• Any of the above complaints • Legionella	• No air filters • Clogged air filters • Duct work or coils oily or dirty • Standing water in air handler • Exhaust/supply air grill dirty • Less than 20° C (68° F) or more than 24.4° C (76° F)	• Add or replace air filters • Clean and disinfect HVAC system • Begin maintenance schedule • Calibrate controls • Balance system

APPENDIX D

MICROBIAL SAMPLING PROTOCOL

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Contamination Recognition

If you see mold growth in buildings, it needs to be remediated and the cause of the growth eliminated. Regardless of the type of biological growth, the recommendation is the same: get rid of it. The IH Branch receives many calls about bioaerosol sampling techniques and exposure guidelines. Standard sampling protocols have evolved over a period of time. However, the results of such sampling are difficult to interpret and no nationally recognized exposure standards for bioaerosols exist. Our recommendation is to first, not sample. If you decide to sample, the guidelines in this section can be used in the development of a sampling strategy. If you are unsure of how to proceed, we can assist you in finding a contractor. Our last recommendation in regards to sampling is to coordinate with a lab that specializes in the analysis of mold, prior to beginning your sampling. AFIERA's lab does not analyze mold samples. They can provide assistance in hiring a laboratory that is qualified to analyze mold samples. The contracted lab will give you the media and often the required equipment. The contracted lab can also assist you with instructions on how to obtain the samples and use of any equipment they provide. It is not recommended that you attempt to use your base medical labs to analyze mold samples.

Sampling for mold is expensive and the return can be very limited. Consider a hypothetical situation where there is visible mold growth in a building. The building has 4 air-handling units (AHUs.) Bioaerosol sampling would be done during the day and during the night with a 7-plate bioaerosol method in each area of the building corresponding to an AHU, one in a non-complaint area, one outside the building, and several blanks (Morris & Shelton 1998.) This hypothetical sampling would result in 88 samples (7 plates * 6 locations * 2 periods + 4 blanks = 88 samples.) The analysis cost per sample depends on the level of identification you want. For gross analysis to the genus level, typical analysis costs are about $50 per sample. This would be a cost of $4,400 for analysis alone ($50*88=$4400.) If you want higher level of identification (e.g. to the species level) the analysis could be up to $300 per plate. This would be a cost of $26,400 for analysis alone ($300*88=$26,400.)

After going through this hypothetical situation, we quickly arrive at the point where we can see that our money would be better spent remediating the problem that is causing the mold growth. The IH Branch strongly discourages bioaerosol sampling. We recommend that if a medical authority requests sampling, they contact the occupational health consultant at AFIERA to discuss the case.

Sampling Factors

Sampling can give you some data. However, interpretation of the data can be very problematic. There are no occupational exposure limits (OELs) for mold, and the ACGIH Bioaerosols Committee has reiterated annually that they cannot recommend Threshold Level Values (TLVs) because of (a) huge sampling variability, (b) huge variability of susceptibility to the workers, (c) large number of different types of bioaerosols out there, and (d) poor exposure-response relationship data. You may compare inside results versus outside results. If the interior levels of airborne mold are much higher than outside, or there are different species than outside, then you may conclude that you have mold amplification (living mold growing) inside. This would indicate that you should remediate the contamination. However, you already know remediation is required if you have visible mold.

If sampling indicates outside concentrations are much higher than inside, you might conclude that there's not a mold problem inside. A good visual inspection would probably have given you the same results. Or there may be visible mold in the building while the air sampling indicated there is no significant problem. False negatives can potentially occur for many reasons. The mold may not be emitting spores due to the stage in its life cycle or something else could have happened to affect the sampling. Would you report that there is no mold problem when the stuff is clearly visible? Mold samples are just one piece of data to be examined when problem solving an IAQ concern.

In some situations occupants may focus on the types of mold. You can obtain bulk, or surface samples, however it really doesn't matter what type of mold exists. If you have visible mold growth you need to remedy the situation.

Sampling Strategies

We do not recommend bioaerosol sampling as a normal aspect of IAQ investigations, but there may be situations where it is required. This may include a request from a medical authority to sample in support of diagnosing a building occupant. Two general sources of sampling, bulk/surface and/or air samples may be useful for detecting amplification of bacteria and fungi in the indoor environment. The following sampling procedures were developed with the assistance of Dr. John Neville (2003) from PK-Jarvis Microbiological, LLC.

Bulk and surface samples

Bulk samples (e.g. wall board, carpeting, ceiling tiles, and insulation) may provide useful indications of the type and amount of bacterial and fungal growth that may be occurring in the indoor environment. Surface samples using cotton-tipped swabs, sterile gauze, or adhesive tape may also be useful for areas where the building material cannot be collected. The presence of trace levels of bacteria and fungi on indoor building materials is normal. Levels of bacteria and fungi that are higher than outdoors may indicate active growth or contamination and thus the presence of a potential health or building problem.

Bulk, swab and surface samples can be assessed directly through the microscope or cultured for mold analysis. Samples that are to be cultured need to be transported to the lab as soon as possible after collection, preferable within 24 hours. To determine the type of analysis to request, consider the following:

Direct Microscopic Examination

Advantages: 1) can determine whether fungal growth or contamination exists or not; 2) fast turn around time; 3) no false negatives; 4) quantify each fungus categorically (i.e. trace, few, many, numerous, and massive).

Disadvantages: 1) limited in fungal identification, since species identity is based on what the fungus looks like in culture (genus level is lowest level of identification possible). The same fungus may look differently on different growing substrates.

Culturable Analysis

Advantages: 1) detect viable fungi; 2) speciation of fungi on malt extract agar (MEA); 3) quantify as CFUs/sample, CFUs/g, or CFUs/inch square (CFU = colony forming unit).

Disadvantages: 1) can't specify whether fungus was growing in sample since it was not directly assessed microscopically; 2) may get false negatives for some fungi because of difference in competitive abilities among fungi for the nutrients in the agar.

Bulk and Surface Sampling Checklist:

1. Bulk
    a. Required Materials:
        i. Clean knife or other cutting tool
        ii. Zip-loc bags
        iii. Alcohol wipes

b. General Procedures: Cut out a piece of building material (i.e. dry wall, sheet rock, ceiling tile) considered to be contaminated with clean cutting utensil (i.e. knife) and place in plastic zip-loc bag and label (a minimum of 1 g of material is required, 25-50 grams of sample is desired if practical**).** Use clean technique, avoiding contamination of the sample. Clean tools with isopropyl alcohol between samples to avoid cross contamination. Bulk samples can be assessed directly through the microscope or cultured for mold analysis.

2. Surface -- Swab or Gauze
   a. Required Materials:
      i. Sterile gauze or swab
      ii. Sterile water or buffer if desired
      iii. Sterile gloves
      iv. Zip-loc bags
   b. Swab: outline specified area to be sampled. An area of 4 to 9 square inches should be swabbed, if area is heavily contaminated, a smaller area may be swabbed. Record area sampled, date and time sample obtained on zip-loc bag or swab tube. Unless you are scanning for the presence of some type of mold, suspected contaminated areas should be compared to areas that have the same type of surface and are considered clean.
   c. Gauze: use sterile gloves to handle the sampling media. The media should be wetted with sterile water or a buffer solution to enhance particle collection. Expel excess liquid prior to obtaining sample.
   d. Wipe specified area (as in swab sample) thoroughly, ensuring full coverage, place sample in new zip-loc bag, label and seal the bag.
   e. Samples should be shipped to lab within 24 hours.

3. Surface -- Tape-lift
   a. Required Materials:
      i. Transparent adhesive tape
      ii. Glass microscope slides
      iii. Clean, protective slide container for transport
   b. Tape-lift samples should be collected using transparent adhesive “scotch” tape. For microscopic examination, the adhesive tape must be of good optical quality. Tape lift samples can only be assessed directly through the microscope.
   c. Use about 2-3 inches of transparent tape. Press tape firmly on suspected contaminated area/surface firmly with thumb.
   d. Following sample collection, exposed tape strips are attached to glass microscope slides (avoiding creases or folds.) Place slide in protective container for transport. Record date, time and place of for each sample collected.

4. Dust Sampling
    a. Required materials:
        i. Dust cassette
        ii. Air pump
        iii. Zip-loc bag
    b. General procedures: Attach a dust cassette to air pump, vacuum as much dust as possible (close face.) A 0.5-gram sample would be an ample amount. Record area vacuumed in square inches. Surface area should be at least one square foot to get enough dust. If you need more dust for analysis then increase the surface area to be vacuumed. Dust samples like bulk samples can be assessed microscopically or cultured for mold analysis.

Air samples

Reasons for collection of air samples are to detect and quantify bioaerosol presence, to identify bioaerosol release from sources, to assess human exposure to biological agents and to monitor the effectiveness of control measures (ACGIH 1999.) However, a negative finding does not prove the absence of the hazard, but indicates only that the hazard was not detected. There are no specific number of bacteria and fungi in the indoor environment that are acceptable or unacceptable. The indoor concentration must be evaluated compared to the outdoor concentration. Usually a minimum of three locations in a building are sampled - an indoor complaint site, an indoor non-complaint site and an outdoor site. The selected locations should be sampled on at least two occasions, thus an air sampling investigation usually involves a minimum of six samples.

The samples are collected directly onto a medium for culturing or a glass slide for microscopic examination. The pros and cons of microscopic versus culture analysis are the same as bulk/surface samples. The air samples must be collected with a calibrated pump for a measured length of time in order to report the findings as cfu/m^3. Determination of sampling time is based upon the suspected level of contamination. Sampling time should be sufficient to obtain the optimal density of fungal colonies on the media without overloading. In general 10 to 60 fungal colonies are considered optimal for accurate counting and identification of CFUs on standard 100-mm plates. For unknown concentrations, multiple sampling times may be needed to obtain the optimal load.

Air Sampling Methods

Air Sampling for Culturable Fungi:

1. Multiple-Hole Impactors (Andersen N-6 type)
    a. Required materials:
        i. Andersen N-6 type sampler or equivalent
        ii. Vacuum pump
        iii. Alcohol wipes
        iv. Sampling media, malt extract agar (MEA) is commonly used for mold
        v. Zip-loc bags
    b. Calibrate vacuum pump to 28.3 liters per minute.
    c. After calibration, wipe all surfaces of the impactor with alcohol wipes.
    d. Remove lid from agar collection plate and place on base plate so the dish rests on the three raised metal pins. Immediately cover the plate with the jet classification stage and the inlet cone. Secure the device with the three spring clamps.
    e. Turn on the vacuum pump for a specified time. Sample time will typically average 5 minutes. Decrease sample time to 2 or 3 minutes if a very high concentration is suspected. Increase time to 7 or 8 minutes if low concentration is suspected.
    f. After sampling, replace the cover of the media and label the back of the plate with location, time, length of sample time and flow rate.
    g. Seal the plate in a zip-loc bag and place in an ice chest with blue ice.
    h. Quality control:
        i. A blank unexposed plate should be analyzed with each sampling event as a negative control.
        ii. Outdoor samples should be collected for comparison.
        iii. Indoor samples should be collected from complaint and non-complaint areas if possible.
        iv. The sampler should be disinfected with alcohol between each use.

Air Sampling For Total Fungal Structures:

2. Slit Sampler (Air-O-Cell cassettes, Burkard, and Allergenco samplers for total fungal structures). Follow manufacturer-operating protocol. The following are sampling procedures for the more common slit air samplers.
    a. Burkard Personal Spore Trap
        i. Required materials:
            1. Burkard personal spore trap

2. Greased slides can generally be obtained from the lab completing analysis.
3. Protective slide case

ii. Ensure the batteries are fully charged before sampling.
iii. Rotate the upper ring assembly until the red dots are in line.
iv. Insert the glass slide through the aperture, adhesive side upwards, until the slide is firmly against the stop.
v. Close the sampling chamber by rotating the knurled ring in either direction at least 1 inch.
vi. Turn on the sampler and sample for desired time. In a routine environment, 5 minutes.
vii. Remove slide and place in protective case for transport. Label with location, time, duration of sample and flow rate.

b. Zefon Air-O-Cell Cassette

i. Required materials:
1. Air-O-Cell sampler
2. Vacuum pump
3. Flexible tubing
4. Zip-loc bags

ii. Calibrate the vacuum pump to a flow rate of 15 liters per minute.
iii. Connect the Air-O-Cell cassette to the sampling pump with flexible tubing.
iv. Remove the tape seal covering the inlet and place on the seal on the side of the cassette for re-use after sampling is complete.
v. Turn on the sampling pump and sample for 5 minutes. Decrease sample time to 2 or 3 minutes if a very high concentration is suspected. Increase time to 7 or 8 minutes if low concentration is suspected. Replace the seal to the inlet after sampling.
vi. Place cassette in a zip-loc bag for transport. Label with location, time, duration of sampling and flow rate.

Discussion

Interpretation of air samples is based upon a comparison of indoor and outdoor fungal concentrations. In well-maintained buildings, indoor fungal concentrations are expected to be similar to, or lower than, outdoor fungal concentrations, particularly where mechanical air filtration devices are present. However, in cold weather climates it is not unusual to find indoor fungal concentrations higher than outdoors. During growing seasons, outdoor fungus spore levels can range from 100 to 100,000 cfu/m^3. Additionally, the rank order and biodiversity of fungal taxa present should be similar in both the indoor and outdoor samples. The presence of atypical taxa, a monoculture, or concentrations above those found outdoors can be an indicator of a fungal reservoir or amplification site.

Microscopic analysis of air samples for total fungal structures, such as those obtained by a spore trap, are evaluated by comparing indoor to outdoor samples. As with culturable air samples your baseline for comparison is outdoor levels. The rank order and biodiversity of fungal taxa present should be similar in both indoor and outdoor samples. The presence of atypical taxa, a monoculture or concentrations above those found outdoors may be an indicator of a fungal reservoir or amplification site.

Cultured bulk and dust samples are evaluated by the number of colony forming units cultured per gram of material and by the surface area sampled. IAQ guidelines developed by OSHA (Instruction CPL 2-2.20B) have suggested that concentrations of culturable fungi in excess of 1,000,000 (10^6) cfu/g of material be considered an indicator of significant fungal contamination. It should be noted that the OSHA Technical Manual states that results in excess of the suggested concentration do not necessarily imply unsafe conditions. A concentration of 10^6 colony-forming units per gram (cfu/g) (+/- 20%) may indicate a fungal reservoir or amplification site and that the presence of atypical taxa, or a monoculture, at concentrations of 10^5 to 10^6 cfu/g suggests a fungal reservoir or amplification site. However, to more accurately present fungal exposure, the mass of each sample and the size of the area sampled should be calculated into the comparison. If all other factors are the same, a large sample area will have more mold than a small one and a dirty surface will have more mold than a clean one. If these factors are not taken into account when analyzing the data, the actual fungal exposure will be misrepresented. This is why accurate recording of all sample data is so important and reinforces the fact that numbers by themselves are of little use when determining fungal exposure.

The lack of fixed reference points in this process cannot be overemphasized. To the best of our knowledge, there are no widely used or accepted national or international standards for what represents a good or bad level of fungus in the environment. As such, interpretation of sampling results should be one part of your overall IAQ survey. What did your visual inspection show? Are the occupants complaining of symptoms that might be due to fungi? Is there a history of water infiltration that could have lead to mold growth? All of these issues should be considered if you find results that seem aberrant.

APPENDIX E

FRESH AIR FLOW RATE CALCULATION

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Fresh Air Flow Rate Calculation

Workers are the only significant source of CO_2 in an office environment; so it is fairly simple to relate CO_2 concentration to fresh airflow using tracer gas theory. Using the steady state CO_2 concentration, the relation is

$$Q = \frac{11{,}500\, n}{C_s - C_a}$$

where Q = fresh air flow rate (cubic feet per minute, cfm),

n = the number of persons served by the air handler,

C_s = steady state CO_2 concentration in the work space (ppm),

C_a = the concentration of CO_2 in the ambient (outdoor) air (ppm),

and 11,500 is a constant based on the average human CO_2 generation rate of 0.0115 cfm per office-worker. This constant comes from ASHRAE 62-1989, which assumes a breathing rate of 9 liters of air per minute and a concentration of CO_2 in the expired breath of 37,000 ppm.

We have verified this equation in several buildings. We use this equation to calculate the fresh airflow required per person to keep the CO_2 concentration at 600 ppm or below. The average outdoor concentration of CO_2 we find on surveys is 325 ppm. Thus, $Q/n = 11{,}500/(600-325)$ = <u>42 cfm/person</u>.

APPENDIX F

HISTORICAL QUESTIONNAIRE

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NAME: ________________________________(optional) SEX: Male Female (circle one)
BASE/CITY__________________ BUILDING__________ ROOM # /LOCATION_______

This questionnaire is being distributed to assess the satisfaction of building occupants with building ventilation conditions. Your cooperation in giving us accurate data is appreciated. Answer the questions below with, **1 = SOMETIMES**, **2 = OFTEN**, **3 = ALWAYS,** only if you feel your symptoms are caused or aggravated by the building environment. Place the number describing the frequency next to the condition. Only one answer per condition.

A.KEY: **0 = NEVER, N/A, or NO 1 = SOMETIMES , 2 = OFTEN, 3 = ALWAYS**

If you have any of the listed symptoms and you feel they are caused by the building, rate the frequency as 1, 2, or 3.

1.____ Aching joints	6.____ Dizziness	11.____ Shortness of breath	16.____ Hay fever or allergies
2.____ Nasal problems/sinusitis	7.____ Dry, itchy skin/rash	12.____ Chest tightness	17.____ Frequent colds/flu
3.____ Back pain	8.____ Headache	13.____ Excessive Coughing	18.____ Bronchitis
4.____ Ear problems	9.____ Excessive Fatigue	14.____ Excessive Sneezing	19.____ Temperature too COLD
5.____ Eye irritation/itching	10.___Excessive Drowsiness or sleepiness; difficulty with concentration	15.____ Wheezing	20.____ Temperature too HOT

21. Other:____

B. When do these symptoms occur?
1. Morning 2. Afternoon 3. Night 4. All the time

C. Do the symptoms get worse as the workweek progresses?
1. Yes 2. No 3. Does not apply

D. When do you experience relief from these symptoms?
1. Upon leaving building
2. When you get home
3. On weekends only
4. Only on extended absences (vacations, etc.)

E. Have you already seen a doctor with your concerns? If so, what were you told?

____

F. Do you smoke? 1. Yes 2. No How many packs per day? ½-1pk, 1-2pk, 2-3pk, >3pk.

F. Where are you located in the building? Floor, etc… ______________________

G. Are you near office equipment? 1. Yes 2. No If so, what type? __________

H. Any other comments you wish to make may be written on the reverse.